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ABSTRACT

This paper provides a summary of information and ideas relevant to the use of computers in science education, describes a variety of uses and strategies, discusses advantages and disadvantages of specific applications, and explores the decision-making process surrounding computer instruction implementation. Uses and strategies which are described include laboratory assistance, simulations, tutorial lessons, drill and practice, and testing. Each of these areas ends with a list of suggested study activities. No attempt is made to teach programming, for this paper presupposes that the reader possesses some skill in either BASIC or FORTRAN, or a language of a similar structure. Appendices contain a listing of a test statistics program and a test item analysis program, and a brief bibliography is attached. (Author/CMV)

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Number 17e

The Illinois Series on Educational Application of Computers

# COMPUTER APPLICATIONS IN SCIENCE EDUCATION

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and

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To the reader,

This is one of a series of documents prepared as resources for the preservice and inservice training of teachers. The general theme of all items in this series is "teaching with or about computers". The booklets are the collective work of a variety of staff and students (both present and former) of the College of Education, University of Illinois at Urbana-Champaign. The project generously was supported between 1977 and 1979 by a grant from the EXXON Education Foundation. All responsibility for the content of these documents rests with the authors and does not reflect necessarily the views of the EXXON Foundation. It was my extreme pleasure to direct this effort throughout.

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# COMPUTERS AND SCIENCE EDUCATION

This paper is designed to provide a summary of information and ideas relevant to the use of computers in science education. A variety of uses and strategies will be described. Advantages and disadvantages of specific applications will be discussed and the decision-making process surrounding implementation will be explored. The ideas and examples presented here are designed to serve as a point of departure for the science teacher who wishes to know more about what the computer can contribute to the instructional process.

No attempt will be made to teach programming in this paper. The authors assume that the reader possesses (or soon will acquire) some skill in either BASIC or FORTRAN, or a language of similar structure. A rudimentary knowledge of computer hardware also will be helpful to the reader, but not necessary.

It has been assumed that the reader may have a somewhat limited knowledge of actual teaching methods and possibly no previous teaching experience. For this reason we have dealt rather extensively with teaching strategies and methodology as they relate to instructional applications of computers. For example, in the section on computer managed instruction, we have explained exactly what is meant by "individualized instruction", how most teachers go about individualizing classes, the advantages and disadvantages of individualized instruction, and how computers might be used to assist with an individualized course.

This emphasis on the methodology of teaching underlines the basic philosophy of instructional computing which we would like to communicate to the reader. We see the computer as a very powerful tool that the science teacher can use--but it is only one of many tools available. Teachers should not use a computer in science teaching just to be using a computer. Rather, they first should establish good learning objectives. If those objectives can best be met by using a computer in the curriculum, then by all means, use one. This is a discussion of how to use computers as a teaching tool, and in particular, as a tool for teaching science.

## IMPLEMENTATION CONSIDERATIONS

The decisions that a teacher makes concerning what activities should be included in a particular lesson are many. We will focus on the planning process in this section. Every lesson should be carefully planned in advance. The planning process, while being somewhat time consuming, results in the most effective use of resources and time and insures that students have the opportunity to learn all that the teacher expects of them. Lessons that incorporate a computer should be as well planned as any other type of lesson, perhaps even more so. (A detailed discussion of planning may be found in ISEAC 3e.)

The teaching process itself can be thought of as having several steps:

1. Goal Identification
2. Objective Development
3. Lesson Design
4. Lesson Implementation
5. Lesson Evaluation
6. Lesson Modification

Each of these steps is necessary if truly good teaching is to be accomplished.

Identifying the goals is the first step in planning any lesson. The teacher must have some idea of what it is the students are to learn and, hopefully, why they should learn it. In the initial stage of planning these goals may be rather vaguely stated--such as:

> The students will learn the factors which affect population growth and how to interpret demographic data.

Instructional goals, generally stated, supply the teacher with a direction in which to proceed.

The second step of the planning process is to break down the broad, general instructional goals into specific behaviorally-stated objectives. Objectives, in contrast to goals, are narrow in focus and provide those specific behaviors which students should be able to demonstrate upon the completion of the lesson. Specific objectives do not need to include every behavior, but, they should be inclusive enough to provide a clear idea of exactly what is expected of the student at the end of the lesson.

It is our feeling that good teaching requires the prior statement of good objectives. We also feel that objectives written in behavioral form are the most concise and useful. It should be noted that well-stated behavioral objectives imply the method of evaluation that will be used to determine whether students have indeed accomplished the objective. This is an important consideration when it comes to the constructing of tests or other evaluation instruments. The words used in the statement of an objective clearly should define the terminal outcome that is expected of the student. This is an important step in the lesson planning procedure. If a particular behavior is to be expected, and tested for, that behavior also should be included in the instructional activities.

Lesson design is the next stage of the teaching process and the one which we will explore in the greatest depth in this section. Once the goals for a class are set and the specific objectives decided upon, the actual teaching strategies can be selected. In designing a lesson, a teacher has to make a variety of decisions. Each teaching strategy or activity should be selected because it is the best available method to accomplish the desired goal. The actual activities must be selected. Lecture, discussion, small group work, laboratory work, student research and reporting, or other acceptable activities may be desirable.

The actual implementation of a lesson will reflect the planning that has been done. A well planned lesson should include all of the activities, topics, methods and materials that will be used and some estimate of the time required for each activity. However, lesson plans should be flexible. The flexibility of approach develops as a teacher gains experience. It is always advisable to include a variety of activities in any lesson since different students learn best in different ways. This variation also is important for maintaining a high level of student interest. Teaching activities which vary will minimize student (and teacher) boredom and insure that learning is maximized.

A lesson is successful only if it accomplishes the objectives for which it has been designed. Every time a lesson is used it should be evaluated, since goals, objectives, and students all may change from year to year. The evaluation of a lesson may involve some student feedback on the appropriateness of the lesson or the activities in the lesson. If teaching is to be an effective and an efficient process, then continuous evaluation is necessary.

The results of the evaluation process may lead to lesson modifications. This is not to say that every lesson must be overhauled completely every time it is to be taught, but rather that the teacher should examine every lesson and perhaps alter it so that it is suitable for a particular class at a particular time. A strategy that works well one time with a group of students may not work with a different group. Teaching and lesson planning both are dynamic processes.

Each of these steps is important to the teaching process. However, we shall concentrate on lesson design involving the computer in some aspect of the instructional activities.

## Some Factors Which Influence Lesson Design and Implementation in Computerized Instruction

Once the instructional goals are set and the objectives outlined, it is up to the teacher to decide exactly what activities will comprise the lesson. This choice is influenced by a variety of factors, such as:

1. Learner Characteristics
2. Situational Constraints
3. Material Availability
4. Hardware
5. Courseware

Concerns about hardware and courseware, of course, particularly apply to lessons involving the computer in some fashion. Each of these factors should be considered before a final choice of instructional activities is made. We will examine each in turn to see how it affects the planning process.

### Learner Characteristics:

Ideally, the teacher should be aware of the learning related characteristics of each individual student. However, this is frequently a task which requires more time and effort than many teachers care to spend. For our purposes, it is enough that the teacher has a good idea of the characteristics of the group as a whole. If the teacher understands that there are many individual differences among the students, then some sort of individualization may be the most appropriate approach for certain topics.

The following characteristics of learners deserve the careful attention of the teacher:

1. Physical maturity
2. Social maturity
3. Reading abilities
4. Familiarity with subject area and presentation medium
5. Attitude toward subject area and presentation medium

In general, it is important to remember that learning does not occur in a vacuum. Students come into any class with a variety of previous experiences and with preformed attitudes. A wise teacher takes these factors into account.

Situational Constraints:

Situational constraints include the physical, temporal, monetary and policy factors present in any school. These must be taken into account when planning any class activity. Many teachers, particularly beginning teachers, plan activities only later to find that they are unable to carry them out. In many cases, there are formal school policies which must be considered. At other times there are no formal policies but merely traditions within a school which can influence the choices a teacher might make.

The following situational constraints should be taken into account when selecting instructional activities:

1. Physical size of the class
2. Location and arrangement of the classroom
3. Amount of time available for class periods and courses
4. District and school policies, rules, and values
5. Availability of funds

Each of the situational constraints listed can influence the choices of teaching strategies and activities a teacher makes. While there is little a teacher can do to control these factors, they should still be considered during the planning process. Careful consideration of all factors which might have any effect, no matter how small, can minimize surprises and last minute changes to lesson plans during the course of an academic year.

## Materials:

The materials and equipment needed for any teaching activity always should be considered by a teacher. Obviously, no teacher would plan an activity that requires unavailable materials or equipment. This requires that a teacher know exactly what is available. However, availability is not the only consideration. All materials also should be appropriate for the class and the activity that is planned. The appropriateness of materials overlaps with other factors previously discussed: reading level, class size, school policy and money.

In most cases it is inadvisable to have students share materials. Thus, there should be a set of whatever materials are required for each student in a class. The reading level of any printed materials should be appropriate for the class in which they are to be used. If it is necessary to order materials or to schedule equipment, then there undoubtedly are school policies and a budget that cover such matters. This is true in the case of audio-visual equipment and materials such as films, projectors, and overhead projectors in most schools. Materials also play an important part when considering the use of a computer in a class. In most schools there is a scheduling procedure which must be followed. It often is advisable to schedule such things as films and computer time well in advance of the time they will be used so that alternate plans can be formulated if the materials or equipment are unavailable. Science teachers are accustomed to considering materials and equipment needed for laboratory experiments. It is our feeling that the same consideration should be given every piece of equipment and any materials that will be used in a class.

## Hardware

Hardware considerations might begin with the computer itself. There are many possible configurations or machines that can be employed in schools. The possibilities range from programmable calculators through micro- and mini-computers to large free-standing, time shared systems. Each of the above systems has advantages and disadvantages. For example:

1. Each type of system typically provides for a certain number of simultaneous users. Large, time-shared systems may be able to have many terminals tied into the computer at any given moment. Micro-computers typically have only one terminal but there may be several of them around. The number of available terminals obviously can have a considerable effect on the planning of an activity.

2. Different computers take different amounts of time to process input data or to run programs. Running a large,

complex program on a small machine may not be feasible because of the time required.

3. Some systems have more storage capabilities than others. Machines with small storage capabilities cannot manage very long programs or store a large number of programs.

Of course, the computer is only part, albeit an important part, of any system. There also is an array of peripheral equipment that must be considered. One of the most important pieces of equipment is the terminal. The terminal is the device actually used to communicate with the computer. There are several different types, the most common being the teletype style or printing terminal. The main advantage of a printing terminal is that a printed copy is available so the student can keep a record of what he or she has done. The disadvantages in some are the relative slowness in printing, the noise made and the fact that such a terminal largely is a mechanical device (mechanical equipment tends to break down often due to the wearing out of the moving parts). Printing terminals are available with a variety of printing speeds. The faster speeds usually are quieter, but the cost may be more than slower models. Cathode ray tube terminals, or CRT'S, are very much like a television. They are extremely quiet and fast, but they do not provide printed (hard) copy. On a CRT once something is displayed and erased it is lost from view. Obviously the speed of operation and the availability of hard copy will be factors that greatly affect the types of uses that can be made of the computer in a class.

The type of terminal available becomes especially important if one is considering the use of a computer program in the batch mode of operation as opposed to the interactive mode. Batch mode requires a hard copy printout for distribution to students. Thus, a paper printing terminal is needed. Also, batch use of a computer usually requires a card or page reader. Card readers are very useful pieces of computer hardware, even though they are not necessary to the use of the computer. Basically card readers take data that has been placed upon computer cards and "read" this data into the computer. The data may be numerical data, lists of words, test answers, or even computer programs. Some readers can only sense information that has been encoded on the cards by a keypunch. A keypunch is a machine that has a keyboard similar to that of a typewriter. However, instead of just typing letters on the card the keypunch also punches holes in the cards. The pattern of holes that is punched is the information. Of course, this type of card reader necessitates the availability of a keypunch and someone who is trained to use it. Another type of card reader can read keypunched cards, but also has the capability to read mark-sensed cards. Mark-sensed cards look the same as punch computer cards and information is encoded upon the cards in a very similar fashion. However, rather than punching a pattern of holes in the card, the user needs only to blacken out certain boxes on the card. All that is required with a mark-sensed card reader are the cards and a pencil.

Having students write their programs on cards eliminates the need for student access to a terminal and thus, saves time. Students can write their programs or encode data on cards and the teacher can then run a number of programs at one time. Of course, not every program can be used in this manner. Tutorial, drill and practice, and some simulations are not adaptable to the batch mode. In other cases student-computer interaction, via an on-line terminal, may be an important part of fulfilling the learning objective of the lesson. Processing of a number of student responses in a group can be done for some simulations and for the analysis of data gathered in lab experiments. In fact, some teachers require that each of their students write a program, on cards, that will analyze the data they expect to get from some experiment. The student then makes the appropriate measurements in the lab and encodes the data on a mark-sensed card and gives the whole stack to the teacher who then runs the data analysis program and returns the print-out to the student.

The availability of a card reader and the possibility of running some programs, where appropriate, in batch mode has little effect on the types of lessons that can be planned. There is, of course, a savings in time, since it takes less computer time to read data and information from cards than it does to have someone type all of the information using a terminal. However, it is important to realize that not every program can be modified for use in the batch mode. In some programs the very interaction between the student and the computer is an important part of the learning process. Batch processing is only appropriate where the information generated by the computer is the important part of the lesson and where complete off-line instructions and explanations of the programs to be run are available.

There are other peripherals (computer add-ons) which can be used to facilitate instruction and which might be found in some schools. These are large TV monitors and plotters. A TV monitor is nothing more than a large TV screen which may be connected to a CRT terminal. When these devices are connected, whatever is displayed on the CRT screen also is seen on the monitor screen. A system like this makes it possible to run a program as a class demonstration, thus, allowing the entire class to see the information on the terminal. In many cases it is desirable to run through a program in this fashion so that the students become familiar with what to expect when they run the program on their own. In other cases some programs may be suitable solely for a large group demonstration and discussion. Simulations frequently are appropriate for use in this manner. Planning for a lesson using a monitor is similar to planning a lesson involving some other type of demonstration, except, of course, for the fact that a reliable CRT terminal and monitor must be available in the classroom.

Plotters are peripheral devices that produce continuous line drawings or graphs. They generally are rather expensive, so their instructional value is not too well tested. However, if data is to be gathered directly from a graph, through measurement, then the availability of very accurate graphs is desirable. Plotters can produce such graphs with relative ease.

In general it is advisable always to test any hardware or equipment that will be used by students to determine what types of difficulties are likely to arise. Some schools, especially those using large time-shared systems, have had problems due to frequent breakdowns of the equipment. An unreliable machine can ruin a well planned lesson. Many teachers avoid the use of the computer even when it is available because they do not want to plan to use something when there seems to be no assurance that it will be working when they need it. The availability or the lack of availability of certain types of hardware can be a limiting factor. It is advisable and strongly encouraged that each teacher fully explore the types of equipment and peripherals that are available and master their operation.

## Courseware

Once goals and objectives have been determined which can best be reached through the use of an instructional program, a decision must be made as to what sort of lesson (tutorial, simulation, etc.) will best accomplish the goals. (The details on courseware preparation in these styles will be found in ISEAC'S 3e, 4e, 6e, 7e, 8e, and 9e.) Once this planning has been accomplished there is only the encoding to be done. The encoding frequently is one of the easiest parts of the whole process. If you are ever in a situation where you feel the need for a computer program that is not available, and have neither the required skill nor the time to do the actual programming, do not hesitate to prepare an outline of the proposed lesson. If you clearly can state what sort of program is desired as an end product, anyone with programming skills should be able to produce it. Some schools have staff members whose duties include production of programs to teacher specifications. If there is a college or university nearby, there may be students who would be willing to undertake the programming chore as part of a class project. Certainly, one should not overlook advanced students from their school. Frequently, there are advanced programming classes or computer clubs that can provide programming services to teachers within the school. Many times such students are excellent programmers who know about the operation of the system and its capabilities and who can produce very useful and sophisticated instructional programs.

It is likely that you will want to produce off-line materials to be used in conjunction with an instructional program. Off-line worksheets or problem sets to be completed through use of the computer. This will provide students with some direction to their work and some clearly defined tasks. The same amount of care and consideration should be spent in preparing off-line materials as would go into production of any instructional program or any other lesson or material that is to be used by a class (e.g., appropriate reading level, legible printing, etc).

As a final note we hope that our discussion of the planning process, especially as applied to the use of instructional computer programs, has not made the task seem more difficult than it is. It is our feeling that planning is time well spent, particularly for the beginning teacher, or for the experienced teacher who is just beginning to make use of instructional programs.

## USING COMPUTERS TO ASSIST IN THE SCIENCE LABORATORY

Laboratory experiences are an essential component of any school science course and a computer can be a very valuable laboratory assistant to both students and teachers. In this section we shall suggest a number of ways in which computer facilities might be employed by the creative teacher in a laboratory program.

### Laboratory Preparation

Science teachers often encounter problems in the management of the laboratory. One of the most common complaints teachers make is that it is difficult to get students to adequately prepare for a laboratory experiment. Ideally, students should read through the entire set of directions for an experiment before coming to the laboratory so that they have a clear understanding of the general procedures and, more importantly, understand why they will follow those procedures. They should know what to look for and have some idea of what results to expect. Without this prior preparation, students tend just to follow the directions step by step in a rather mindless fashion, not understanding what they are doing or why they are doing it.

Most science teachers stress the importance of pre-lab preparation. Yet, it is common to overhear one student asking another, usually as they are putting on their lab aprons, "What experiment are we doing today?" Not only do ill-prepared students fail to learn much from the laboratory experience, but they present a laboratory safety hazard. Pupils who do not understand what they are doing often make mindless errors which result in accidents.

Teachers have tried, with various degrees of success, a number of different techniques designed to force students adequately to prepare for laboratory experiments. Some teachers refuse to permit students to bring their laboratory manuals into the lab but rather require students to bring whatever directions they need on an index card. The reasoning is that if students are forced to condense the lab instructions in this manner, they more likely will understand the experiment. This method works fairly well but many students just copy the lab instructions word for word and really do not think about what they copy. Other students make such brief notes that once they get into the lab, they find they don't have enough information to do the experiment.

Another approach which has been tried often is giving students a pre-lab quiz before every experiment, or at least frequently enough that students expect them. This method has an advantage in that it really forces students to study the experiment, hopefully to the point where they understand it. Unfortunately, pre-lab quizzes take time, of which there seldom is enough. Too often no more time is allowed in the school schedule for laboratories than for regular classes. It is very difficult for most students to complete an experiment in a period, and if you take away 10 minutes at the start of the period for a quiz, the problem is exaggerated.

A computer might be employed, at least partially, to solve the problem of ill-prepared student experimenters. One often used technique is based on the pre-lab quiz idea but overcomes the shortcomings of this approach in that time is not taken from the laboratory period itself. With this approach the teacher prepares a list of questions based on the experiment and distributes these questions to the students about one week prior to the scehduled date of the lab period. The students are instructed to read the lab, answer the questions, and finally to sign-on to the computer and enter their answers in a special lab program. This program proceeds to grade the answers and if the student meets a predetermined minimum criterion, prints out a 'lab ticket.' The student then presents this lab ticket to the teacher at the start of the laboratory period as evidence of having passed the pre-lab exam.

Several variations of this method are possible. Rather than actually typing the quiz answers into the computer on-line, students could record the answers on mark-sensed cards which then could be batch processed, the program then prints a list of those students cleared for lab. With more elaborate computer systems, the pre-lab quiz could be handled in an interactive mode with perhaps some tutorial components to the program. In any of these methods, it is important that enough lead time be allowed so that students who fail to pass the pre-lab quiz the first time can study the experiment some more and repeat the quiz.

A third approach which could be used in more advanced science courses is to require students to come to lab with a program they have prepared to analyze the data collected in the experiment. Of course, this approach requires some programming skills, but elementary BASIC could be taught at the beginning of the course in a relatively short period of time. This technique has several advantages. First of all, a student really must understand the experiment in order to write an appropriate data-analysis program. Secondly, with an analysis program in hand, the student rapidly can analyze results, generally the same day as the experiment, while the whole thing still is fresh in mind. If the student prepares the program on mark-sensed cards and enters collected data in the same manner, the programs for a whole class can be processed in a short period of time.

There are possible disadvantages to this technique. It may be unreasonable to expect less capable students to be able to write their own programs, thus, the method may be applicable only to more advanced science classes. Secondly, students might be tempted to "fudge" data. The teacher would have to be vigilant for unusually good results. Finally, not all science experiments require mathematical analysis. This technique would not be of much help in a biology lab on the physiology of the frog. However, within its limitations, this approach seems to be rather promising.

## Lab Breakage Accounts

Traditionally science teachers have charged students the replacement cost of broken glassware. The problems of collecting money from students complicates this process and some schools have implemented a policy of absorbing the breakage loss within the science department budget. However, with the ever-present shortage in budgets and with students tending to be a bit clumsy, this approach often does not work. If students know that they will not be charged for breakage, they tend to become even more clumsy, a somewhat natural human characteristic. Thus, most schools still have some kind of a breakage policy.

A solution to this is to set up a program which will keep individual student breakage accounts. The program can contain, in a data file, the current per item cost of every piece of labware a student might use. Then, during a laboratory period when breakage occurs, all you have to do is enter the student's name and the name and size of the broken item. The computer would look up the cost of the item and record that along with the item name, size, student name, and the date. At appropriate intervals throughout the year, you could request a listing showing what each student has broken, when this occurred, and how much each item costs. Everything is nicely documented and listed, which helps eliminate any arguments. However, more importantly, it only takes a few seconds for the teacher to enter the breakage record into the program. You can immediately get back to supervising the experiment in progress, which possibly might prevent still other accidents.

## Inventory of Supplies

Another modification you could make to a breakage program would be of considerable value. This modification could provide the teacher with a listing of breakage by item. This would be useful at the end of the year when it's time to order next year's supplies. The program could give you an exact listing of how many beakers were broken, and of what size; how many flasks were broken, and so on. If desired, you even could run an inventory at the beginning of the year and enter the number of each item on hand. The breakage program then automatically could subtract broken or discarded items from this list, providing you with an up-to-date list of exactly what was on hand at any given time.

You could extend this program to include expendable materials such as chemicals. Again, you could start the year by doing an inventory of the chemicals on hand, estimating to the nearest ounce. You then could estimate approximately the amount of each chemical that is required per student for every experiment you do during the typical year. As the year progresses, just enter the experiment number and the number of students doing the experiment. The program could estimate the amount of each chemical which should be consumed and deduct this amount from the balance on hand. The result is an up-to-date inventory of chemical supplies available at any moment.

Let's go still one more step and enter your favorite supplier's catalog number for each item. Then enter another set of data: the minimum quantity of each item you wish to keep on hand. The computer then automatically can print out a requisition on request complete with item catalog numbers and names, ready to submit to the department chairman for approval.

If you do this, be sure to make the inventory program flexible. It should be easy to add new items to the program. Likewise, it should be easy at any time to add items to the order list which are not included in the inventory file. For example, you may not wish to include ringstands in the automatic inventory, as they are not expendable and usually do not break. However, if you decide later that you need more ringstands, you should be able to enter that into the program to be included on the next order. The computer will then remember to include them on the next requisition listing. (A sample inventory program is described in ISEAC 24e.)

## Teacher-Prepared Lab Analysis Programs

There are two ways in which computer programs may be used to assist students in analyzing laboratory data. One is to have the students write such programs themselves as a pre-lab activity. A possible disadvantage to this is that students first must be taught the rudiments of computer programming, a task requiring already scarce class time. For this reason you, as the teacher, may prefer to develop such data analysis programs for the students. Teachers of science long have felt that science students often become bogged down in the mathematical calculations and lose sight of the main points of the experiment in the process. Indeed, some students dislike science mainly because so much mathematics generally is required. This problem at least partially is eliminated if students can concentrate on the experiment and not worry about the calculations. This by itself, is sufficient to justify the time required of the teacher (or advanced students) to program the computer to accept student data, to calculate, and to print out results.

It would be a good idea to design data analysis programs in such a way that the output not only gives the results but illustrates the required calculations, step by step. Let's take a specific example and see how a lab data analysis program might look to the student. Suppose your class is doing an experiment in lab to determine the molecular weight of oxygen gas. The experiment is done by heating a small quantity of potassium chlorate, collecting the resulting oxygen gas produced and measuring its volume. By weighing the test tube before and after heating, the weight of this gas can be determined. Here's how the program could look to the student (underlined portions are typed by the student):

```
PROGRAM GMWO2

THIS PROGRAM WILL COMPUTE THE GRAM MOLECULAR WEIGHT OF
OXYGEN GAS FOR EXPERIMENT TEN.  YOU WILL NEED TO ENTER THE
FOLLOWING DATA:

1.  THE ORIGINAL WEIGHT OF THE POTASSIUM CHLORATE PLUS TEST
TUBE
2.  THE WEIGHT OF THE TEST TUBE AND CONTENTS AFTER HEATING
3.  THE MEASURED VOLUME OF OXYGEN GAS COLLECTED IN LITERS
4.  THE TEMPERATURE OF THE WATER BATH
5.  THE BAROMETRIC PRESSURE IN THE LABORATORY AT THE TIME
OF THE EXPERIMENT

DO YOU HAVE ALL OF THIS DATA?  YES

OK.  ENTER THE DATA BELOW AS REQUESTED.  OBSERVE THE UNITS
REQUIRED!

ORIGINAL WEIGHT OF TEST TUBE PLUS POTASSIUM CHLORATE (GRAMS)
?  7.70
WEIGHT OF TEST TUBE AND CONTENTS AFTER HEATING (GRAMS)
?  6.70
MEASURED VOLUME OF OXYGEN GAS COLLECTED (LITERS) ?  0.795
TEMPERATURE OF THE WATER BATH (DEGREES CELSIUS) ?  18.0
BAROMETRIC PRESSURE (TORRS) ?  740

WHAT IS YOUR NAME?  SHARON
FINE, SHARON.  WHAT IS YOUR LABORATORY NUMBER?  136
THANK YOU.  HERE'S HOW WE CALCULATE YOUR RESULTS:

FIRST OF ALL, THE FORMULA FOR THIS REACTION IS--
2 K CL 03 = 2 K CL + 3 O 2
NOTE THAT ONLY THE OXYGEN GAS ESCAPES FROM THE TEST TUBE, SO
THE CHANGE IN WEIGHT, WHICH IN YOUR CASE IS 1.0 GRAMS
```

(7.7 GRAMS - 6.7 GRAMS), MUST BE DUE TO THE OXYGEN WHICH ESCAPES. THUS WE HAVE DETERMINED THE WEIGHT OF THE 0.795 LITERS OF OXYGEN GAS YOU MEASURED.

HOWEVER, YOU MUST REMEMBER THAT THE GAS WAS NOT UNDER STANDARD CONDITION OF PRESSURE AND TEMPERATURE WHEN YOU MEASURED ITS VOLUME. BEFORE WE CAN CALCULATE THE GRAM FORMULA WEIGHT OF OXYGEN, WE MUST FIRST CORRECT THIS VOLUME TO STP.

YOU REPORTED A BAROMETRIC PRESSURE OF 740 TORR. HOWEVER, SINCE THIS GAS WAS COLLECTED OVER WATER, WE ALSO MUST TAKE THE VAPOR PRESSURE OF WATER INTO CONSIDERATION. WHEN COLLECTING GAS OVER WATER, THE PRESSURE OF THE GAS ACTUALLY IS EQUAL TO THE ROOM PRESSURE MINUS THE VAPOR PRESSURE OF THE WATER.

THIS IS BECAUSE THE GAS INSIDE THE CYLINDER CONSISTED OF WATER VAPOR AND OXYGEN GAS, EACH EXERTING A PARTIAL PRESSURE WHICH TOGETHER EQUALS THE ROOM PRESSURE.

THE TEMPERATURE OF YOUR WATER WAS 18 DEGREES CENTIGRADE. AT THAT TEMPERATURE THE PARTIAL PRESSURE OF WATER VAPOR IS 15.5 TORR. THUS THE ACTUAL PRESSURE OF THE OXYGEN GAS IN YOUR EXPERIMENT WAS:

$$740 \text{ TORR} - 15.5 \text{ TORR} = 724.5 \text{ TORR}$$

NOW, WITH THIS IN MIND, WE CAN SET UP AN EQUATION TO CONVERT THE VOLUME OF OXYGEN GAS TO STANDARD CONDITIONS:

$$0.795 \text{ LITERS} \times \frac{724.5 \text{ TORR}}{760 \text{ TORR}} \times \frac{273 \text{ K}}{291 \text{ K}} = 0.703 \text{ LITERS AT STP}$$

NOTE THAT WE CONVERTED THE WATER TEMPERATURE (18 DEGREES CENTIGRADE) TO KELVIN DEGREES (18 + 273 = K). REMEMBER, IT IS ABSOLUTELY ESSENTIAL (GET IT?) TO CONVERT TO ABSOLUTE TEMPERATURE WHEN USING THE GAS LAWS!

FINALLY, WE KNOW THAT AT STANDARD CONDITIONS ONE MOLE OF A GAS WILL OCCUPY 22.4 LITERS OF VOLUME. HOW MANY MOLES OF OXYGEN DID WE HAVE? WE CAN FIGURE THAT OUT IN THIS MANNER:

$$\frac{0.703 \text{ LITERS}}{22.4 \text{ LITERS/MOLE}} = 0.031 \text{ MOLES}$$

. . . AND, SINCE WE KNOW HOW MANY GRAMS OF GAS WE HAD (1.0 GRAMS), WE CAN CALCULATE THE NUMBER OF GRAMS PER MOLE, WHICH IS THE GRAM FORMULA WEIGHT:

$$\frac{1.0 \text{ GRAMS}}{0.031 \text{ MOLES}} = 31.9 \text{ GRAMS/MOLE}$$

THIS IS AN EXCELLENT RESULT, SHARON! HERE IS A SUMMARY OF

```
THE RESULTS REPORTED BY OTHER STUDENTS SO FAR:

NUMBER OF STUDENTS REPORTING SO FAR: 18
RANGE OF VALUES CALCULATED:
     HIGH: 36.8 GRAMS/MOLE
     LOW: 26.1 GRAMS/MOLE
MEAN VALUE FOR GRAM FORMULA WEIGHT OF OXYGEN CALCULATED:
30.8 GRAMS/MOLE
STANDARD DEVIATION OF CALCULATED VALUES: 3.1 GRAMS/MOLE

BASED ON YOUR RESULTS YOU HAVE BEEN AWARDED 25 OUT OF A
POSSIBLE 25 POINTS.
YOU CAN CONSIDER THAT AN "A".


RUN COMPLETE
```

There are several features in this program which you may or may not like. Note that the program assigned a certain number of points at the end based on the accuracy of the experiment. You may not want this feature in lab analysis programs. An advantage to this style of program is that the student can, if you have some kind of printing terminal, leave the lab with a detailed analysis of the experiment showing the exact calculations and explaining the reasons for them. The student can keep this copy for future reference and the teacher might well assign some similar problems for the student to work out on his/her own.

Another nice feature is that the program keeps track of the results of previous students and prints out a summary of the results reported so far. This gives the student some idea of the variation which occurred in the experiment, and how accurate his/her results are as compared to the results obtained by others. Hopefully, the mean value will converge to the accepted value as more and more students enter their data. Students often fail to get this information without assistance of some form.

Also, as time goes by the teacher will be able to perceive a very clear idea of how accurate various experiments are. Having the mean calculated values and the standard deviation of values for a number of experiments, he/she may find that one or two are inaccurate as reflected by a high standard deviation. In such a case, the teacher may wish to modify the experimental techniques or perhaps substitute a similar, but more accurate, experiment.

## Information Programs

Another type of program which would be useful in the science laboratory might be called the "information program" or "library program". Let's define these types of programs as ones which are designed to permit the student to access useful information in a short period of time. Here are some examples of what might be tried:

1. A program dealing with laboratory safety. An interested student or faculty member could type in the name of a chemical compound or piece of laboratory apparatus and the computer would give any information on hazards which might otherwise be overlooked. As an example, if a student typed in SILVER NITRATE, the computer might respond: POISONOUS-- DO NOT TAKE INTERNALLY. SOLID AND SOLUTIONS SHOULD NOT BE PERMITTED TO COME IN CONTACT WITH SKIN. CAUSES BLACK SPOTS ON THE SKIN WHICH DO NOT APPEAR FOR SEVERAL HOURS. SKIN MAY DIE AS A RESULT. EXPENSIVE! DO NOT WASTE. (The programs described in ISEAC 24e could be used for such programs.)

2. A program which keeps track of where particular pieces of laboratory equipment are to be stored. Student might type in: RUBBER STOPPERS and get: STORED IN DRAWER NUMBER 23, ROOM 231. (ISEAC 24e applies here too.)

3. A program which would permit a person to enter the chemical formula for a solute, desired solution concentration in moles/liter, and the desired volume of a solution, and would proceed to calculate the number of grams of the solute and number of ml. of water needed to produce the desired solution.

## Miscellaneous Programs

There are a few other types of programs which might be of some assistance in the laboratory. If you use an open-lab teaching technique, one in which students report to lab as needed during free time, you might want to keep records on the time each student spends in the lab. This information could be kept on the computer. In an open-lab, you occasionally may find it necessary to schedule the use of a particular piece of equipment. The computer could manage this scheduling for you. Tutorial programs on the proper technique for using a certain piece of lab equipment, such as an analytical balance, also might be useful. There probably are many other ways that a computer could assist you with your laboratory program. If you don't think of them, your students probably will!

## STUDY ACTIVITIES

1. Discuss the advantages and disadvantages to having science students learn computer programming a) in science class, b) in mathematics class, c) not at all.

2. Analyze the teaching day of a science teacher. Identify other ways a computer might be used to assist such a teacher.

3. From a text in your field, select a laboratory experiment and write a computer program that might be used to facilitate that experiment. Your program might administer a pre-lab quiz, provide data analysis, or provide pre-lab practice on the procedure, etc.

# COMPUTER SIMULATIONS IN SCIENCE EDUCATION

Simulations offer the teacher a powerful aid for teaching a wide variety of concepts. In this section we will discuss the application of simulation to the teaching of science. Detailed information concerning the nature and use of simulation in general may be found in ISEAC 8e in this series.

Many computer simulations involve models which can be expressed using mathematical relationships. For example, Kepler's model of the solar system could be described using a drawing or diagram but if put on a computer it must include the formulae for the elliptical orbits of the planets. With these formulae, the computer could be instructed to produce a diagram of the solar system (or parts thereof) within the graphic capabilities of the display device being used.

The algorithms for many simulations are neither simple nor easy to develop. A great deal of time and study is necessary to discover the variables involved, their initial values and the relationships among the variables within the environment. Many of the relationships in a phenomenon are difficult to determine with any degree of accuracy, and some of the variables are difficult, if not impossible, to measure. However, for many instructional purposes a "perfect" model is not necessary. It may be unnecessary for a simulation to be as scientifically complex and accurate if it is to be used as an instructional aid rather than for scientific research. In fact, in many cases simulations such as the Metre Apex Simulation, used to study urban air pollution, may be _too_ complicated and difficult for use with a particular group _of_ students. A simple simulation, such as POLUT, a Huntington II simulation dealing with waste treatment and water quality, may not be appropriate for use by engineers planning a new water treatment plant but it can provide students with an opportunity to discover the various factors which might influence the water quality of a given body of water. In many educational situations complex simulations may serve only to confuse students rather than to clarify concepts and ideas. There can be value in using simulations based on models which are known to be incomplete or in some way inaccurate. Even imperfect simulations permit the user to gain skills in problem solving and in determining relationships among variables, and the exercise of comparing a simulation model to real life can be very useful.

## When Are Simulations Useful?

As with many educational innovations, there are many misuses of simulations. A simulation should never be used merely because it is available. Simulations should be an integral part of the science curriculum and lessons should be planned accordingly. Simulations should not be used to replace all "hands on" experiences. As the work of Piaget and many others has shown, "hands on" experiences are a necessary part of the learning process. However, there are situations in which "hands on" experiences for students are impossible or inadvisable. For example, among the first uses of simulations for instruction was the use of flight simulators. Using these simulators, beginning pilots could practice many of the skills required during an actual flight. The use of simulators provided this experience at a much lower cost and with considerably less risk to life and property than actual flight. Another early use of instructional simulations, and one that still is common, was in medical training programs. Using simulations medical students practice diagnostic techniques with no risk to patients. Also, they learn to recognize the symptoms and to prescribe treatment for diseases they might encounter only rarely in actual practice.

Some factors which can make simulations preferable to more direct student experience are:

1. the cost of the necessary equipment
2. possible danger to students or others
3. laboratory or study techniques that are difficult to master
4. experimental time scales that are either too long or too short to be dealt with in a classroom situation
5. the inability to experiment directly.

Any of the above is suitable justification for the use of a simulation. For example, in the Huntington II simulation POLUT students are able to explore the effects on water quality of various amounts and types of wastes which are dumped into a body of water. Obviously, an experiment which replicates this process in the real world would be impossible to carry out, even if it were desirable. There are many available simulations which deal with genetics and the crossing of various species. In this case, the time scale and the difficulty of the necessary laboratory technique make the use of a simulation highly preferable.

Simulations may provide ways of realizing educational goals which are unobtainable using other means. There have been several studies of the use of simulations in classrooms. Some of the benefits which have been reported are: increased enthusiasm and motivation among students; the realization of the importance of good communication skills; forced decision making, sometimes on the basis of incomplete data; learning to accept the results of and the responsibility for previous decisions, regardless of their quality; and, the role of teamwork and responsibility in many situations. Certainly, some of these goals could be accomplished using more conventional techniques but the use of computer simulations is a relatively easy way of insuring that the above objectives are accomplished. Computer simulations also provide students with valuable experience in problem solving in situations which closely approximate real life. Also, some researchers have reported that the use of simulations requires that students master the skills required to extract information from procedural symbolic systems. These are different skills than those necessary to extract information from conventional educational materials (sentences and pictures).

Of course, as with any educational development, there is less than total agreement as to the possible benefits of the use of simulations in general and computer simulations in particular. Critics of the use of simulations point out that there is a lack of data on the educational value of such experiences. Simulations require rather large expenditures of both time and money to produce and utilize. Also, simulations usually require that the users be able to deal effectively with multi-variate systems.

The types of learning that can be facilitated through the use of computer simulations are as many and varied as are the types of simulations. The development of models and the construction of simulations is in itself a valuable learning experience. However, as stated previously, the development of a simulation is not an easy task and may well be beyond the capabilities of many students or require more time than can be justified. Fortunately, there are many simulations that have been developed by various groups and which are available commercially. Undoubtedly some of these simulations will exist on any computer system you are likely to encounter. Hewlett-Packard provides several simulations to schools using their hardware. The Huntington II project developed many excellent simulations for classroom use. These are distributed by the Digital Equipment Corporation. The Huntington simulations are especially good since they provide off-line materials which explain the simulation, offer background information and provide lesson ideas and questions for the teacher and student.

Some computer simulations are based on complex real situations. In these the student user can explore and discover the effects of various factors on the simulated situation. An example of this type of simulation would be the Huntington II simulations POLUT and USPOP. In each of these simulations there is little attempt at telling the student what the results will be or exactly how the various factors influence each other. This type of simulation ideally is suited for open-ended, inquiry approaches in which the student largely is free to investigate the simulated situation on his/her own.

## The Laboratory Simulation

Another type of computer simulation is the computer simulated laboratory (CSL). In this type of simulation, an actual experiment is simulated and the user operates as the experimenter. There are many examples of this type of simulation. Huntington's TAG simulates an experiment in population sampling using tagged fish and SLITS simulates Young's experiment on double slit interference. Others simulate experiments such as Milliken's oil drop experiment or simple acid-base titrations. Computer simulated labs offer one of the most powerful uses of simulations in science teaching, but one that is not without some discussion as to its benefit.

Laboratory work plays an important part in science learning and has become an increasingly large part of the science curriculum in most courses. A familiarity with lab equipment and the methods of its use should be a part of the objectives of any science course. Computer simulated labs should not be used to replace any actual lab experience for students. However, there are situations where a simulated experience can be valuable. In any laboratory experiment, the types of activities to be learned can be classified in two separate, but inter-connected, categories. First, there is the logic of the experiment or the thought process involved on any experiment. Second, there is the mechanics or performance part which involves the actual manipulation of the laboratory apparatus. Computer simulated labs can provide ways of learning the logic even in situations where the necessary apparatus is not available. For example, in the simulation TAG, students can learn the logic of animal population sampling. To perform the actual experiment would require that the students have access to a lake with fish in it, tagged fish, a boat, and other equipment. Few schools have these facilities. However, there is even value in using simulations of easily performed experiments, such as titrations. By having students try several simulated titrations, during which they can concentrate on the logic of the experiment, they are better able to understand the actual titration process once they have a chance to perform the experiment in the lab. In fact, having students "practice" with simulated labs may insure that they have read the lab and will be more familiar with what is expected of them when they perform the experiment. The question of whether or not to use simulated labs depends on the particular teaching setting and on the objectives which the teacher has for the exercise.

Some guidelines to be considered when contemplating the use of computer simulated labs are:

1. Simulated labs can expand student experience in cases where the real experience is too costly, too dangerous, too remote, or too out of scale with the available time and resources.

2. Simulated labs can include experience with the logic of arranging apparatus, obtaining readings, and interpreting data. However, basic operations with measuring devices and other apparatus should be performed at some point.

3. Simulated labs should replicate the actual experiment as closely as possible. Any worksheets, tables, or other materials that would be required in the actual performance of the experiment should be required in the simulation.

4. Whenever possible, a computer simulated lab should be preceded by a demonstration of the experiment being simulated or by a video-tape or film of the experiment. This should be followed by a discussion or other teaching method to insure that students fully understand the purpose and logic of the experiment.

5. Simulated labs should be followed by having students actually perform the lab exercise whenever and wherever feasible.

As useful as computer simulated labs may be it should be realized that not all types of laboratory exercises can be simulated using a computer. Labs that call for observational data rather than measurements may not be suitable. For example, it might be difficult to simulate a lab involving the dissection of a frog. It should also be noted that there are simulations that require special hardware, or that only operate on a specialized computer system.

## How Can Computer Simulations Be Used In A Science Classroom?

In many cases classroom teachers have little control over many of the factors which influence their course. Frequently, scheduling and textbook selections are made without consulting the teacher. Usually, however, the teacher has a great deal of freedom in determining what teaching methods and activities will be used in a particular class. Of course, the methods and activities utilized must be within certain boundaries. For example, methods or activities which endanger students or property, or which are disruptive to other classes, probably will be severely frowned upon by other teachers and administrators. The concerns which should be foremost in a teacher's mind as he or she considers using a computer simulation are the same concerns which should precede any decision about instructional methods and activities, with a few additions. These concerns include the instructional objectives, the learner characteristics, situational constraints, available hardware and software, and other needed material or equipment previously discussed. Of these, only questions about available hardware and software are unique to instructional use of computers. For a more detailed account of the process a teacher should complete while deciding whether or not, and how, a computer simulation should be used, see Dirks, 1975.

Because of the wide variability of hardware and school situations it is difficult to discuss with any degree of certainty the sort of instructional plan which might be developed for the use of a specific computer simulation. However, it is instructive to look at what others have done. The following is a brief, incomplete view of what a teacher might go through when considering the classroom use of the Huntington II simulation, POLUT. In this example the class is a senior high school environmental science class. The use of the POLUT simulation makes the evaluation and planning processes somewhat easier than with other simulations since the off-line materials provided offer possible objectives and activites. The Teacher's Guide offers the following discussion of the use of POLUT (Williamson, et. al., page 3):

> Many relevant social problems today center on the management and quality control of natural resources. In the process of becoming well informed, responsible citizens, students at the secondary school level should acquire some understanding of and insight into these ecological problems. The POLUT unit capitalizes on a manageable portion of the mammoth water pollution problem. It provides a context within which students can gain substantial understanding of the basic scientific and economic factors involved in the water pollution problem. Using the medium of the computer, students can investigate the effects of variables, compare various pollution control strategies, examine hypothetical situations, make and test hypotheses, and predict the implications of certain scientific and economic decisions. Such a degree of student involvement is in stark contrast to that which is traditionally available and can significantly enhance the student's interest and learning. In addition, the student is able to experience an active process of inquiry.

A possible set of instructional goals or objectives for a unit which incorporates the POLUT simulation follows (Dirks, et al, pages 22-23):

> When a student has completed a unit of study centered on the POLUT program, he or she should be able to:
> 1) Briefly describe the process of waste breakdown in water, and the importance of oxygen to this process.
> 2) Describe or identify the effects of each of the following variables on a water body's ability to handle waste:

-- the type of body of water;
-- the water temperature;
-- the type of waste released into the water;
-- the rate of dumping waste;
-- the type of waste treatment.

3) Describe the effects that reduced oxygen levels in water can have on the life of fish.
4) Briefly describe the process of primary waste treatment and the process of secondary waste treatment.
5) Given an instance of water pollution, the student can do the following:
   - -- provide a crisp statement of the problem;
   - -- list some areas where more data is needed;
   - -- describe some alternative courses of action;
   - -- describe impediments to the implementation of the solutions;
   - -- select a single alternative, then provide justification for its selection, perhaps using data generated by the POLUT simulation, identify several interested parties and describe their feelings and attitudes toward the problem and proposed solution.

The above list does not include many of the general objectives of most science courses which might also be fulfilled through the use of the POLUT simulation. For instance, students, through their use of POLUT, might also be expected to be able to deal with the interpretation of data, the scientific method, the construction of models and simulations and a variety of activities involving values clarification. The above objectives primarily are dealing with the content included in the simulation. Notice that the objectives are stated in a fashion that implies how the attainment of the objective will be evaluated. It should be understood that the above list is only a partial list of objectives which reflect the thought of a hypothetical teacher. It is expected that if *you* were going to use the POLUT simulation in a class, you would want to include many of your own objectives.

The statement of objectives, however clear and well designed, does not imply much about teaching strategies or activities. The same set of objectives may result in many different lesson plans. The actual process of lesson planning must take into account learner characteristics, situational constraints and available hardware and courseware. The above objectives, along with others not listed, could have resulted in a variety of possible lesson plans. For example, the following unit plans both arise from the same set of objectives (from Dirks, *et. al.*, pages 25 to 27 ). Both plans have been developed *for use in* a senior high school environmental science class. While the lesson plans are somewhat general, they do imply that considerations of learner characteristics and hardware, among other things, have been made.

## PLAN FOR A UNIT ON WATER QUALITY USING THE POLUT SIMULATION:

DAY ONE: Trip to local sewage treatment plant.

DAY TWO: Class discussion: 1) processes of waste treatment; 2) role of oxygen in water quality and waste degredation; 3) Biochemical Oxygen Demand (BOD) and the BOD/OXYGEN sag model; 4) types of waste; classifications of water bodies; 6) the relation of water temperature to dissolved oxygen concentration; 7) the relation of dissolved oxygen concentration to the activity of game fish.

DAY THREE: Trip to water treatment plant.

DAY FOUR: Class discussion: 1) finish topics not completed on Day Two; 2) introduce students to the computer system; 3) introduce POLUT to students. Hand out specific problems to be explored and solved through the use of POLUT.

DAY FIVE: Students work polut.

DAY SIX: Class discussion: 1) help students with the graphing of the data; 2) help students interpret individual graphs; 3) students share data produced with POLUT; 4) help students synthesize results. Hand-out open ended problems to be explored and solved using POLUT.

DAY SEVEN: Students work with POLUT.

DAY EIGHT: Class discussion: 1) results of yesterday's work; 2) experimental methodology; 3) assumptions and accuracy of the POLUT model.

DAY NINE: Trip to local "polluting" industry.

DAY TEN: Class discussion: impressions of yesterday's trip; 2) economic factors concerning water pollution. Prepare class for values clarification exercise, perhaps a role playing game.

DAY ELEVEN: Values clarification exercise.

DAY TWELVE: Values clarification exercise.

DAY THIRTEEN: Evaluation.

The above effort is a good beginning for a unit plan but needs to be more complete if it is to be used. Each day should be broken down carefully to describe the specific activities that will be included. The amount of time that will be spent on each topic or activity should also be estimated. It is helpful to make a notation of how the individual activities relate to the instructional objectives.

The second plan is merely a topical outline and does not include any of the actual teaching strategies or materials. It may be considered as a beginning effort which will be extended and clarified before the actual unit is taught. This plan might be the type of outline produced when a teacher is considering the sequence of units for an entire year or semester course.

## TOPICAL OUTLINE FOR A UNIT USING THE POLUT SIMULATION:

FIRST WEEK: Water lab: An investigation of samples of local waters. The samples are tested for turbidity, pH, dissolved solids and microscopic life. Discussion of the chemistry of water: This would include the chemical formula of water, its specific heat, the concept and role of dissolved oxygen, typical aquatic food web and Man's uses of water and proposed needs for water in the future. Appropriate audio-visual materials should be used. Field trip to a water treatment plant or a model of a plant in class.

SECOND WEEK: Discussion of waste degredation on water; Biochemical Oxygen Demand; the types of waste and their effects on natural aquatic systems. Discuss sewage treatment. Field trip to local sewage treatment plan and/or a major water using industry. Introduction to and discussion of the POLUT simulation.

THIRD WEEK: Work with the POLUT simulation: Students will be given specific tasks (individually or in small groups) to determine the effects of the parameters available for change on the simulated system. Discussion and comparison of the results of changing the variables in POLUT. Work with the POLUT simulation: Students will be given (individually or in small groups) open-ended projects dealing with water quality and report to the class as their solutions for a particular problem and their reasons for their choice.

FOURTH WEEK: Discussion or outside speaker on water quality laws and/or local water pollution problems and possible solutions. Values clarification exercise such as a role playing game and/or designing advertising campaigns against water pollution. Evaluation.

Planning lessons incorporating computer simulations is an important step in insuring that the many potential benefits of the use of simulations are realized. The process should not be taken lightly. Many teachers seem to feel that comprehensive lesson plans are unnecessary. This may be true for lessons centered on more traditional activities with which the teacher and students likely are to be familiar. However, it is felt that because of the relatively recent development of computer simulations teachers should spend a good deal of time preparing for lessons which incorporate simulations. It is expected that once teachers and students become familiar with such activities, the planning process will become easier and less time consuming. The planning process can be seen as trying to build a lesson around an appropriate simulation. Alternatively, a teacher might wish to modify a computer simulation to more exactly suit the purposes in mind.

## Modifying Computer Simulations and Courseware.

Most teachers have few qualms about skipping chapters in a textbook or altering the order in which topics are covered. In most schools, unless there is a strictly adhered to syllabus, the teacher is free to teach in most any appropriate manner or order. Many experienced teachers rely heavily on units and materials that they have developed themselves or adapted from other sources. However, few teachers seem to make the same sort of modifications and adaptations of computer simulations.

Modifications of computer simulations can be considered in four categories:

1. modifying the mode of operation

2. altering the output

3. altering the model

4. changing the setting

In addition, modifications may be made to any off-line materials that are part of the simulation package.

The great majority of computer simulations are designed to be operated in the interactive mode. That is, each student interacts individually with te simulation. One of the easiest and most useful modifications is to change a simulation so it can be operated in the batch mode. This modification is, of course, only feasible if a card reader is available. Batch operation especially is useful if mark sensed cards (those on which responses are encoded using only a pencil) are availabe.

The batch mode of operation can be a great help in planning for the use of a simulation. It provides the teacher with increased flexibility. The interactive mode requires enough terminals for the class and enough time for each student to run through the simulation. This can be a problem especially if the terminals are located in a room other than the science classroom.

Use of a simulation in the batch mode eliminates this problem. Students can mark their responses or data on the cards which can then be carried to a computer room and processed. Depending upon the nature of the simulation and the time required for a run, it may be possible for a hard copy of the results to be returned to the students by the end of the class period. Alternatively, it may be desirable to collect the cards at the end of a class period and to run them during a free period or after school (when the computer is not being heavily used) and to return the results to the students the next day. In either case, a fairly fast printing device is desirable. The fast printing device minimizes the amount of time needed for one run of the program with student data.

Use of the batch mode in this fashion eliminates some of the spontaneity and immediate feedback possible through the interactive mode. It also requires that several days be allocated for computer work since it is possible for students to run only one or two sets of inputs through the simulation on a given day, unless they submit cards for several runs, each with different input data. If this last course is taken it is possible for students to complete several runs in the time it might take to run one or two interactively. However, when using the batch mode, students react more slowly to the data supplied by the simulation.

The actual modifications to the simulation program necessary to change it from interactive mode to batch mode are relatively simple. First, some provision must be made for identifying an individual student's run. Second, interactive input statements (INPUT in BASIC) should be changed to batch style data reading statements (READ in BASIC). Third, default conditions must be set up in case the submitted data falls outside acceptable limits established by the model. If default conditions are necessary, some notice of this must be on the print-out which the student will receive. Fourth, any directions or instructions, which were provided on-line in the interactive version must be available in off-line form. Those portions of the program which print the on-line directions can be deleted from the program.

Following is an example of some changes necessary to the Huntington II simulation POLUT to modify the program for use in the batch mode. In the interactive version the student is asked to provide values for five variables: type of water body, water temperature, type of waste treatment, type of waste and the rate of dumping. Also, the student has an option to choose from one of three types of output: tables, a graph or both. The appropriate responses have been described in the off-line materials. On the terminal the student would see:

```
WATER TEMPERATURE?
```

In this example the student has input a water temperature of 27 degrees Fahrenheit, although it is not necessary for the student to include the units. For this variable there is an acceptable range of inputs of 33 to 99 degrees. If, for instance, a student were to attempt to input a water temperature of 27 degrees Fahrenheit in the interactive mode, the computer would respond with:

```
WATER TEMPERATURE?  27
YOUR BODY OF WATER IS A BLOCK OF ICE AND CAN'T ACCEPT
ANY WASTE.  TRY A NEW TEMPERATURE.
WATER TEMPERATURE?
```

The program code which produces this output is:

```
425 PRINT "WATER TEMPERATURE";
430 INPUT
435 IF T > 90 THEN 1055
440 IF T<=32 THEN 1070
 .    .    .
1070 PRINT "YOUR BODY OF WATER IS A BLOCK OF ICE AND CAN'T"
1075 PRINT "ACCEPT ANY WASTE.  TRY A NEW TEMPERATURE."
1080 GO TO 425
```

This is the way the code appears when written in BASIC. Each of the five variables is input through a similar process, one at a time. In the batch mode all of the inputs are made at once using a DATA card. If the information on the card were written out in BASIC it might look something like this:

```
1083 DATA "SMITH",1,57,2,9,0,2
```

This card would be submitted to the card reader along with the necessary control cards which, depending upon the system hardware, will access the program and begin execution. In place of the INPUT statements for each variable there can be a single READ statement at the beginning of the program which automatically will access the next set of data.

```
45 READ A$,W,T,U,R,S,X
47 PRINT A$;W;T;U;R;S;X
```

The PRINT statement provides a way of identifying each student's output and also provides a record of the data being input for the student. Of course, if one wished, it is possible to provide titles or identifying information for each of the input data. Once the data is read into the program the execution procedes as usual. However, should a student try to input a value for a variable that is outside the acceptable range there is no chance of changing it as in the interactive mode. It is in this instance that a default value must be provided or the program will pause in execution and wait until an acceptable value is input. For example:

```
435 IF T>90 THEN 1055
440 IF T<=32 THEN GOSUB 1070
 .   .   .
1070 PRINT "YOUR BODY OF WATER IS A BLOCK OF ICE AND"
1072 PRINT "CAN'T ACCEPT ANY WASTE.  YOUR TEMPERATURE"
1075 PRINT "HAS BEEN CHANGED TO 35 DEGREES."
1080 PRINT " TRY TO BE MORE CAREFUL IN THE FUTURE."
1085 LET T=35
1090 RETURN
```

In this example if a student were to attempt to input a value that is too low he would receive a message on the output telling that the value had been changed to 35 degrees. Default routines must be included for each variable that has a limited acceptable range for input.

While the changes necessary to alter a program from interactive to batch operation are not difficult, changes to any program should be thoroughly checked and the entire program debugged to insure that it is operating correctly. It should also be understood that not all simulations are suitable for operation in batch mode. Some programs require complex inputs that might be difficult to understand without the cues provided in the interactive mode. Others offer so many options that the possible input choices cannot be handled easily using DATA statements. Still others may not provide the same type of experience in batch mode as they do in the interactive mode and thus might be inappropriate to fulfill the objectives the teacher has in mind. Any changes should be thought out and planned before being attempted. It strongly is suggested that all such modifications be made on a duplicate version of the simulation being modified so that the original will remain intact and both versions will be available for future use.

An additional modification which should be considered when changing a program from interactive to batch and which might also be desirable if a simulation is to be used interactively is changing the form of the output. Operating in batch mode provides more student runs in a shorter period of time. If students continually choose output options which involve long graphs or tables, any savings in time may be lost. For batch mode the output should be as short as possible and still provide the desired information. In other cases there may be an option for a graph of the data when a table would be more appropriate, particularly if the teacher wants the students to develop skill in graphing data from tables. In other cases the form of output may not be suitable for the students' reading level. As with any other type of educational activity, simulations and the output data from simulations should be matched to the level of the learners. If it is not deemed suitable by the teacher it should be changed.

Another modification which might be considered is the altering of the setting of the simulation. Frequently the setting is provided by off-line materials so that this modification may not require any changes to the program code. Simulations take on more meaning if the simulated situation can be related to local situations and problems. In the case of POLUT it may be desirable to alter the setting so that it deals with local bodies of water and local waste disposal problems. Making the setting locally relevant can result in increased student interest and insure that the learning will be likely to be remembered.

A final modification, and one that should not be undertaken lightly, is the altering of the simulation model itself. If, in the opinion of the teacher, the model is not accurate enough to suit the instructional purposes for which the simulation is being considered, the model must be changed. However, as mentioned before, the development of models is not an easy process. Typically a great deal of work has gone into the preparation of simulation models. Again, if changes are to be made, they should be made on a duplicate version of the program so that the original can remain intact. In some cases, such as with advanced classes, a teacher might wish to make a model inaccurate and give the class the task of testing and modifying it so that it agrees more closely with reality. The process of determining the correct model for a simulation through repeated runs of the simulation can be very helpful in aiding students' understanding of the process of model building and simulating.

## Summary

A simulation is an attempt to replicate some process or situation in nature. The use of simulations in school can be advisable if the actual experiment would be too dangerous, costly or time consuming. Some types of simulations currently are available commercially, especially computer simulated laboratories. Computer simulations can be used in existing science curricula. The factors which should be examined when evaluating a simulation for possible use and when planning lessons incorporating simulations are: hardware, instructional objectives, learner characteristics, situational constraints and courseware. Modifications which a teacher might make to an available simulation so that it would be more appropriate for classroom use are: changing from interactive to batch mode of operation, altering the output, altering the setting and modifying or producing off-line materials.

## STUDY ACTIVITIES

1) Identify a phenomenon in a science course you (will) teach, and discuss the ways a batch version of a simulation and an interactive version of it would be used to teach the concepts surrounding this phenomenon.

2) Take any simulation available on a convenient computer system (or one published in a book). Make a batch operable version of the program. (Try to do this on a computer that has a batch input facility so that you can debug your work.)

# THE USE OF TUTORIAL LESSONS IN SCIENCE EDUCATION

Tutorial lessons are used to present new information to the student, usually in the form of displayed text interspersed with questions. Tutorial lessons are among the most difficult to write and, usually, are most demanding of both hardware and supporting software. For example, the "exact" matching of responses necessary to evaluate an answer input by a student makes free-form text judging difficult, especially in the BASIC computer language. Some software languages (TUTOR, PILOT, or COURSEWRITER) are specifically designed to be more flexible when evaluating student responses. Although tutorial lessons can be very useful in the teaching of science, it will be some time before a selection of such materials becomes commercially available for a variety of school computers. A more detailed discussion of tutorial lessons is found in ISEAC 6e.

## The Structure of Tutorial Lessons

To a great extent tutorial lessons follow a pattern which is similar to that found in printed programmed instruction books. New knowledge is presented in small increments and the student is questioned immediately on that new knowledge. As in printed programmed instruction, there should be a great deal of feedback to the student. In tutorial lessons quick and appropriate feedback is an important part of the learning process.

Unlike printed programmed instructional lessons, tutorial lessons which are computer-based can more easily allow for multiple paths through the material to be learned. The actual path taken by any given student is determined by performance on included quizzes. These quizzes often are not very extensive, and may consist only of a single question or problem.

The lesson begins with an introduction section--an advanced organizer, or a set of instructions. After the introduction, the lesson asks a question or series of questions about the first objective as a pretest.

The student who is unfamiliar with the material represented by the first objective is taken to a section of the lesson that presents information about the objective. After the student has read the new information, he/she is questioned over that material. If this post-test is completed, the pretest for the next objective is given. If the post-test is not completed, the computer checks to see if the author of the lesson has included additional information on the current objective. If so, it presents that additional information and then re-tests the student. This cycle continues until either there is no more information stored in the program or until the student passes the post-test on the objective.

In many tutorial lessons the type and nature of additional information given a student will depend upon responses to questions. That is to say that a particular incorrect answer may indicate a misunderstanding and cause the program to present additional information designed to correct that specific misunderstanding. In other tutorial lessons the computer may present the same additional information regardless of the incorrect answer.

In this type of lesson the length of time required to complete the lesson depends entirely on the student's performance on the post-tests. The successful student will be taken through the lesson rapidly. However, the student who has difficulty will move more slowly and receive a larger amount of information and assistance.

To a great extent, the success of a particular tutorial lesson depends upon how well the author can anticipate and provide for incorrect or unexpected student responses. The best tutorial lessons have extensive branching with very specific help sequences triggered by specific incorrect responses.

In tutorial instruction, a large amount of information is presented to the student. Generally, this information is printed or displayed as text, which must be read by the student. It is very awkward to do tutorial lessons with computer facilities that cannot rapidly display quantities of text. For example, a typical teletype printer is rather slow for such purposes and it tends to frustrate the students. We recommend that you restrict use of tutorial lessons on any computer system that is not equipped for rapid output.

There is another approach to this slow output problem. Textual material can be reproduced in handout form and the program designed such that the computer refers the student to the appropriate sections of the handouts, perhaps by number. The worst type of tutorial lesson is one which consists of vast quantities of textual information only occasionally punctuated with interactive questions.

## Using Tutorial Lessons in Teaching Science

One of the advantages of tutorial lessons is that once they have been made operational, they are always available. Because of the limitations imposed on the use of tutorial lessons by the amount of available time, possibly the best use of these lessons is to provide remedial help for the less able student. Thus, tutorial lessons can be used as supplements in the instructional program, rather than as the instructional program itself.

Probably tutorial lessons initially will be used infrequently. For this reason, we suggest that you examine, in detail, some of the existing tutorial lessons rather than developing them yourself. Possibly the best way for becoming aware of the possibilities and difficulties of tutorial lessons is by looking carefully at several examples. Techniques for evaluating computerized lessons and an evaluation form will be found in ISEAC 5e.

## DRILL AND PRACTICE IN SCIENCE EDUCATION

Essentially a drill and practice lesson is designed to reinforce the learning of some simple skill or knowledge through repeated trials, such as the learning of a list of vocabulary terms, or perhaps a type of mathematical problem to be practiced. In any case, the skill to be learned is one which can be learned through repetition. Repetition is the key characteristic of a drill and practice lesson. (See ISEAC 7e for a detailed discussion of the effective design of drill and practice lessons.)

Drill and practice programs have been very popular. Because repetitive tasks are often simple and well-defined, the interaction between student and computer is often itself simple and easily definable. Programming needs are often not extensive and therefore many students may be handled with a relatively small investment of time and resources. There are not many drill and practice applications in contemporary science. The nature of drill and practice lessons is such that they tend to stress rote memorization and the mastery of simple repetitive skills while current science teaching stresses understandings, processes and relationships. However, almost every subject involves some of this typeof learning which a computer system greatly can optimize.

### Possible Drill and Practice Applications in the Sciences

A drill and practice lesson might be useful at any time in a science course when the teacher feels that there are some facts or terms which should be memorized by students. Likewise, drill and practice type lessons can be used to give practice in solving mathematical problems of a specific type--although a lesson dealing with complex mathematical problems might very well be classified as a tutorial lesson. Here are a few examples from each of the science fields of topics which might form the basis of a drill and practice lesson:

Biology.

1. The student of biology often encounters new vocabulary terms which must be learned. These terms and their meanings could form the basis of a drill and practice lesson in which the computer presents a definition and asks the student to type in the correct term or vice versa.

2. The student of biology frequently is asked to learn to identify structures of living organisms by name. Drill and practice lessons can be designed around this task. If the available computer system has graphical displays, the computer can be used to picture these structures as the student names parts. Another way of accomplishing the same thing is to give the student diagrams on handouts with

the structures to be identified numbered. The drill and practice lesson can then just refer to the structures by number, again asking the student to type in the name of the numbered structure, or alternatively may give the name of a structure and ask the student for the number of its location in the drawing.

3. Generally the student encounters the metric system for the first time, at least on an application level, in biology. A drill and practice program can be constructed around the use of the metric system. Such a program might ask questions such as: "How many centimeters are there in 3.25 meters?" In this program the numerical constants can be randomly selected by the computer.

Chemistry. Some of the ideas mentioned above might also be appropriate for chemistry. But let's look at a few applications specific to chemistry teaching:

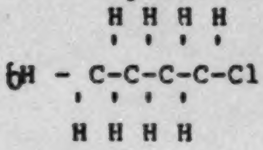
1. Most chemistry teachers still require students to learn the chemical symbols for the most common elements, although some have even abandoned this practice arguing that students naturally will learn those symbols that they use frequently. Nevertheless, computerized lessons can be useful in assisting students with the learning of these symbols. Common radicals also can be included in such lessons.

2. A more complex drill and practice lesson can give students practice in equation balancing. A lesson presents a series of unbalanced equations and asks students to supply the correct coefficients. Still more complex would be a program which would present two or more reactants and ask the students the formulae of the products as well as the necessary coefficients for balancing the resulting equation.

3. Few teachers require students to learn oxidation states (valences) anymore, prefering them to use a periodic table to obtain such information. But if you feel students should know the more common oxidations states, by all means, develop an appropriate drill and practice program to facilitate this learning.

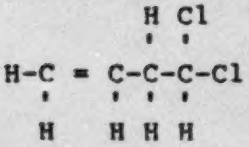
4. In the field of organic chemistry, nomenclature is a topic around which an excellent drill and practice lesson can be constructed. The only problem here is that special graphics might be needed to illustrate

the structure of some organic compounds, but the more simple organic molecules can be illustrated on a regular teletype. As an example:



$$\mathrm{OH-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-Cl}$$

NAME? 4-chlorobutanol



$$\mathrm{H-\underset{H}{C}=\underset{H}{C}-\overset{H}{\underset{H}{C}}-\overset{Cl}{\underset{H}{C}}-Cl}$$

NAME? 4,4-dichlorobutene

Physics. The most obvious applications of drill and practice lessons in physics teaching are lessons which give students practice in the solving of problems. We'll illustrate with two examples here.

1. Every physics course, be it traditional, PSSC, or Project Physics, deals with simple kinetics. A drill and practice lesson can be designed to give students practice in applying the laws of mechanics to solve problems. Example:

   > A student drops a lead ball from the top of the Sears Tower in Chicago (1059 ft.). What will be the velocity of the ball when it strikes a pedestrian in the street? (Ignore air resistance and assume the pedestrian is exactly 6 feet tall.)

   A problem template can be used in such cases to generate many similar problems:

   > If a lead ball is dropped from a height of __X__ feet, what will be its velocity on impact?

   In this format the computer inserts randomly chosen numbers for the variable x, within a range specified by the teacher, and then calculates the correct answer to be compared with the student's response. Through such a system, every student can have different practice exercises.

2. Gas laws are another topic that can be the basis of a drill and practice lesson similar to the one suggested above. In fact, any content which requires practice in mathematical formulas can be the subject of a drill and practice lesson.

## Considerations in Designing Drill and Practice Lessons

The drill and practice lesson should follow the general considerations mentioned earlier regarding objectives, learner characteristics, situational constraints, available material, hardware, and courseware. Following are additional considerations to keep in mind when designing or selecting a drill and practice lesson:

1. How much terminal time can be used for the lesson? Even if terminal time is no problem it is generally unwise to design a drill and practice lesson which takes more than 30 or so minutes. Research suggests that computerized drill and practice sessions lead more rapidly to fatigue than text exercises.

2. What is the criteria for completing the lesson? In the example physics problem drill listed above, the criteria for completion was three problems in a row correct. The criteria for this same lesson could have been set at just three correct--not three in a row. There is an infinite variety of completion criteria possible. You, as the designer of the lesson, must decide what the criterion will be. The student should be aware that there is a definite end to the lesson and of what must be done in order to reach that end.

3. On many computer systems it is possible to place a time limit on each problem in a drill and practice lesson. This can be a useful feature in lessons designed to improve speed in performing a task. If you want students to be able rapidly to identify terms, then it might be a good idea to allow only a specified time for responding.

4. On any question the correct answer should be provided if a student gets the answer wrong. You may, however, wish to design the lesson such that the student is allowed more than one chance before the answer is given. Occasionally it may be desirable to include a brief explanation of how the correct answer is obtained, particularly in science lessons dealing with problem solving.

5. At the completion of the lesson there should be some provision for giving the student feedback on his performance. This may simply consist of a statement telling how many items were missed and how many were correct, or it may be more complex and evaluative in nature.

6. Try to personalize the drill and practice as much as possible. Use the student's name in the lesson, use informal rather than stilted English, and use humor where appropriate. Students tire quickly of dry, rigidly repetitive lessons.

## STUDY ACTIVITY

Here is a very simple example of a drill and practice program which can be used by a physics teacher to give students practice on gas law variable relationships:

```
10 REM THIS PROGRAM ALLOWS STUDENTS TO PRACTICE SOLVING GAS
20 REM LAW PROBLEMS.  THE STUDENT SHOULD HAVE A HAND
30 REM CALCULATOR HANDY TO WORK ON THIS PROGRAM.  NOTE
40 REM THAT IN ORDER TO FINISH THE PROGRAM, THE
45 REM STUDENT MUST GET THREE PROBLEMS IN
50 REM A ROW CORRECT.
60 PRINT"WELCOME TO GAS LAWS!  (THIS PROGRAM IS A GAS!)"
70 PRINT
80 PRINT
90 PRINT"WHAT IS YOUR NAME"
100 INPUT N$
110 PRINT
120 PRINT"OKAY, ";N$;" LET'S GET STARTED.  I AM GOING TO"
130 PRINT"GIVE YOU SOME PROBLEMS RELATED TO THE CHANGE"
135 PRINT"IN VOLUME OF GASSES DUE TO CHANGES IN"
140 PRINT"TEMPERATURE AND/OR PRESSURE.  YOU MAY NEED A"
150 PRINT"HAND CALCULATOR TO CARRY OUT YOUR CALCULATIONS."
155 PRINT"IN ORDER TO BE COUNTED CORRECT, YOUR ANSWER"
160 PRINT"MUST BE CORRECT TO THE NEAREST MILLILITER"
165 PRINT"(0.001 LITERS).  PLEASE EXPRESS ALL OF YOUR"
170 PRINT"ANSWERS IN MILLILITERS!"
180 PRINT
200 PRINT"YOU MUST GET THREE PROBLEMS IN A ROW CORRECT"
210 PRINT"BEFORE YOU FINISH.  I WILL KEEP TRACK OF ANY"
220 PRINT"MISTAKES YOU MAKE, SO BE CAREFUL!  TRY NOT"
230 PRINT"TO MISS ANY.  NOW, HERE IS YOUR FIRST PROBLEM:"
240 PRINT
250 PRINT
260 LET M = 0
270 LET C = 0
280 LET P1 = INT(RND(-1)*500)+400
290 LET P2 = INT(RND(-1)*500)+400
300 LET T1 = INT(RND(-1)*60)+230
310 LET T2 = INT(RND(-1)*60)+230
320 LET V1 = INT(RND(-1)*3000)+50
330 PRINT"A CHEMIST HAS ";V1;" MILLILITERS OF A GAS AT A"
340 PRINT"TEMPERATURE OF ";T1;" DEGREES KELVIN AND A"
350 PRINT"PRESSURE OF ";P1:" TORR.  WHAT"
360 PRINT"VOLUME WILL THIS GAS OCCUPY IF THE"
365 PRINT"TEMPERATURE CHANGES TO ";T2;" DEGREES KELVIN"
370 PRINT"AND THE PRESSURE CHANGES TO ";P2;" TORR"
380 INPUT V2
390 LET A = V1*(P1/P2)*(T2/T1)
400 IF INT(A) = V2 THEN 470
```

```
410 PRINT"SORRY, " ;N$;" THAT IS NOT CORRECT.  THE CORRECT"
420 PRINT"ANSWER IS ";INT(A);" MILLILITERS.  YOU NOW HAVE"
430 PRINT"MISSED ";M+1;" PROBLEMS.  LET'S TRY "
435 PRINT"ANOTHER PROBLEM."
440 LET M = M+1
450 LET C = 0
460 GO TO 280
470 LET C = C+1
480 PRINT"VERY GOOD, "N$;"!  THAT IS CORRECT.  YOU NOW HAVE"
490 PRINT C;" PROBLEMS IN A ROW CORRECT!"
500 IF C = 3 THEN 530
510 PRINT"YOU ONLY NEED ",3-C;" MORE.  HERE'S THE NEXT."
520 GO TO 280
530 PRINT"YOU'RE NOW FINISHED!"
540 PRINT"YOU MISSED A TOTAL OF ";M;" PROBLEMS DURING"
545 PRINT"THIS DRILL."
550 IF M = 0 THEN 570
560 GO TO 600
570 PRINT"THAT IS SUPER!  GOOD FOR YOU.  YOU'RE"
580 PRINT"REALLY A GAS!"
600 END
```

Using the above program, implement this version or a similar version on an accessible computer system. Have several students execute your program and record observations about their work (positive and negative observations).

## COMPUTER-ASSISTED TESTING AND EVALUATION IN SCIENCE EDUCATION

Testing and evaluation are a vital part of any teaching method. You will recall that a model of the teaching process previously was discussed. The teacher begins by deciding what learning outcomes (objectives) are appropriate for a particular course. After the outcomes have been specified, learning experiences are designed aimed at helping students meet these specified outcomes. The resulting plan may or may not include computer-based experiences. It is the teacher's task to decide what kinds of learning experiences will be most efficient and successful in helping students meet the outcome objectives. Once a sequence of learning experiences has been planned, the plan is executed, and the result is evaluated.

Testing and evaluation in this model of teaching play a dual role. Of course, testing normally is required as a means of assigning course grades to students, but even more important is the role testing plays in evaluating the learning experiences which were designed by the teacher. At the completion of a planned unit of study, it is the teacher's task to scrutinize both the original unit objectives and the prescribed learning experiences. At this point, the teacher must consider several points. First of all, was the unit successful? Did the majority of students accomplish the specified learning objectives? If so, then the prescribed learning experiences were successful. However, even in this situation the teacher should consider whether there might be other learning experiences which would be even more successful. If, on the other hand, the teacher finds that the unit was not successful, that a considerable number of students failed to meet one or more of the specified outcomes, then several things need to be examined. For example, were the learning objectives appropriate for the students? Were appropriate instructional strategies or materials chosen? Does the evaluation instrument test what is being taught in the materials?

The lesson design process is cyclic: specification of outcomes, prescribing learning experiences, testing, and then final evaluation of the whole process. Hopefully, this model of teaching will lead, over the years, to increased success. However, the important point here is that testing should not be an afterthought. The testing phase of this teaching model is as important, as the other stages. The construction, administration, and interpretation of tests are valuable skills which a teacher must learn early in a teaching career.

Essentially, there are four ways in which a computer can be utilized in assisting with the testing and evaluation process:

1. test generation

2. test administration

3. test scoring

4. test analysis

We will examine each of these, suggesting specific applications in the teaching of the sciences. A more detailed discussion of these topics is found in ISEAC 12e.

## Types of Tests

Tests and test items generally are categorized as either subjective or objective. Subjective items are those which perhaps could best be described as open ended: there is no clearly defined correct answer, but rather a set of possible answers. An essay question is a good example of a subjective test item. While the teacher may have in mind some general expected responses, a student's answer can vary significantly from this expectation and still be correct. Thus the scoring of subjective items demands judgment by the teacher. Subjective items seldom are judged all right or all wrong. They are correct to a certain degree. It remains the task of the teacher to determine this degree of correctness.

Objective items, on the other hand, are designed so that there are definable correct responses. The student's answer either is correct or is incorrect. Judgment is not required in the scoring of such items and any person, even one totally unfamiliar with the content matter covered by the test, can score objective items if given a test answer key.

Those who favor subjective items argue that the higher behaviors of the cognitive domain (Described in Bloom's *Taxonomy of Educational Objectives*), such as synthesis, analysis, and evaluation, can *only* be evaluated using such items. Supporters of objective items disagree, saying that any level of the cognitive domain can be measured using well-designed objective items. While this point is debated, there are recognized advantages and disadvantages of each type of item. We briefly summarize these here.

Tests which are predominantly subjective are comparatively easy to make up. Unfortunately, any time saved in the designing of a subjective test is more than lost in the scoring process. Grading a subjective test is an arduous task made even more difficult by the teacher's desire to be fair and impartial. Because it takes students longer to respond to subjective test items, fewer such items can be included on any test. This means that the test may sample understandings of only a few topics presented. Such a limited sample may or may not be representative of the students' overall learning.

The reliability of subjective tests is low and grading practices tend to be inconsistent. Most teachers will admit that the score a student ultimately receives on a subjective test depends somewhat on where the test was in the pile of tests to be graded. Teachers are influenced in their grading, at least to some extent, by their mood and by the test papers which they already have read. For this reason it often is suggested that a set of subjective test papers be graded by grading all papers on question one, then all papers on question two, and so on. Subjective tests may give unfair advantage to the verbally-oriented student. Some students write so well that even when they don't know the answer to a question, they verbalize in a manner that easily can mislead the teacher.

Finally, perhaps the strongest feature of subjective tests is that they tend to encourage more than simple recall. The students' abilities to analyze complex situations, to synthesize a whole from parts, and to evaluate can be stimulated more easily by the use of subjective tests.

Objective tests are considerably more difficult to construct than subjective tests. However, once an objective test is constructed the majority of the work is completed. Using an answer sheet and punched key, a teacher or an aid rapidly can grade a test. Since it takes much less time to respond to an objective test item, a relatively large number of items can be used, thus providing for wide sampling of the subject being tested. This provides a more representative picture of what a student actually knows about the tested topics.

The reliability of objective tests varies with their quality, but generally is much higher than for subjective tests. Like subjective tests, objective tests may give unfair advantage to particular students. Students can become "test wise" in taking objective tests and will score higher, generally, than students who do not have as much experience in taking such tests. Some teachers attempt to overcome this bias by instructing all students at the beginning of the school year in test-taking skills.

## Types of Objective Items

There are several different types of objective test items. An objective test may be made up of several of these types of items in combination, or it may be made up exclusively of one type. Each of the item types has advantages and disadvantages.

True-False. One of the more commonly used item types is the true-false. These items are very easy to make, but unfortunately this ease leads to serious abuse by most teachers. It often is too great a temptation to make true-false items simply by taking sentences directly from a textbook. Such items generally are very poor for testing. Often they test simple recall of the most insignificant facts.

Another disadvantage of the true-false item is that even the student who knows absolutely nothing should, by chance alone, get half of the items correct. Some teachers attempt to overcome this problem by instructing students to respond "always, sometimes, or never" to such items. Other teachers instruct students to correct false statements so that they are true, but this considerably complicates the scoring of the test papers. Still other, more complex true-false schemes have been tried. Some teachers have made up items consisting of two true-false items which are related. As an example:

18. Dogs are animals ___ because ___ dogs have hair.
    To respond to this item mark:
    1. If both the statement and the reason are false,
    2. If the statement is true but the reason is false,
    3. If the statement is false but the reason is true,
    4. If the statement and reason are both true, but the reason is not adequate to explain the statement,
    5. If the statement and reason are both true and the reason adequately explains the statement.

While this more complex true-false format may be useful, it can be very confusing to the student.

Here are some guidelines for making true-false items:
--Avoid taking statements directly from a textbook,
--Avoid the use of the terms "always", "sometimes", "seldom", "never" in true-false statements. These words cue the observant student.
--Make sure that a true-false item is a single statement. Example: "Lead is heavy because it is a metal" is difficult to mark true or false. It is true that lead is heavy. It is true that lead is a metal. It is not true that lead is heavy because it is a metal.
--In making up true-false statements, try to make about half of them true and half false in any given test. Mix them as randomly as possible, and avoid patterns in responses such as two false, two true, two false, etc.

*Multiple choice.* The multiple choice item consists of a statement or question, called the *stem*, and a set of alternate responses. One of the responses is the correct answer and the other (incorrect) responses are called *distractors.* Multiple choice items are popular among teachers, but are very difficult to write. Here is an example:

STEM 18. At the right is a diagram of a swinging pendulum. At what position does the pendulum have the most *kinetic* energy?

1. Position A
DISTRACTORS 2. Position B
3. Position C
ANSWER 4. Position D

Multiple choice items can be very useful if properly prepared. In constructing multiple choice items, the teacher should observe the following:

--The stem of a multiple choice item should pose a clear, unambiguous problem by itself and should be a complete sentence.

--Make the stem as concise as possible without sacrificing clarity. Do not include unnecessary information in a stem.

--There should be one and only one clearly *best* response among the alternatives. The distractors, however, should seem reasonable to the student who does not know the answer. None of the distractors should be ridiculous to the point where they are automatically eliminated by even the most naive student.

--Negatives, such as "not" or "never" should be underlined in the stem, or such words should be written entirely in capital letters. If this is not done, students often will overlook the negative. Some experts recommend avoiding negatives in items.

--Insofar as possible, alternatives should be similar to one another in structure. Avoid making the answer fairly long and all the distractors fairly short or vice versa. Avoid using words in the answer which are synonyms for words in the stem.

--The correct answer should appear in each position of the alternatives lists about equally often and the order of positioning from one item to another should be random. For example, sometimes try to obscure the correct answer by avoiding the first alternative position. Students quickly catch on to this.

--Avoid the use of "none of the above" or "all of the above" as choices.

*Completion or Short Answer.* The completion item is an item which has a single word, phrase, or number as a correct answer. Items of this type may take the form of fill-in-the-blank sentences or may require student calculations resulting in a numerical answer. Such items frequently are used by science teachers due to the nature of the science curriculum. Following is a summary of suggestions for writing completion type items:

--Be sure that there is only *one* correct answer.
--When replacing words of a statement with blanks:
  a. omit only significant words of the statement.
  b. avoid omitting words that cause the meaning of the statement to be lost.
  c. replace words farther into the statement after a clearly defined problem has been stated.
--Avoid grammatical or other clues to the correct answer.
--Keep blanks of a uniform length.
--Avoid statements taken directly from the text.
--Limit the required answer to a single word or simple phrase.

*Matching.* The final type of objective test item that will be reviewed is matching items. A matching item consists of a list of terms, symbols, names, or even diagrams (called *stimuli*) and a set of identifying statements (called *responses*). In completing matching items, the student selects a response from the list which best matches each stimuli. All material in a matching item should be related in one way or another. For example, the terms should all be names of scientists, chemical symbols, or perhaps diagrams of laboratory glassware to be identified.

Following is a number of suggestions concerning the design and use of matching items in testing:

--Be sure to include clearly stated directions with matching sets. These must include a statement of the basis on which matching is to take place. Include notice whether or not a response might be used once, more than once, or not at all. Also describe how to record answers.
--Stimuli should be listed in a column on the left and responses in a column on the right. There should be more responses than there are stimuli so that at least some are not used. This helps to avoid students getting items correct simply by the process of elimination.
--List the responses in some order that facilitates their location during responding but does not cue the answers (alphabetically, chronologically, etc.)
--Avoid grammatical or other irrelevant cues.
--Limit the stimulus list to at most ten.
--Minimize the reading time of all parts of an item.
--Material in a matching set should be related by a common theme.

Matching items tend to emphasize simple recall of facts. If you find you are using a large number of matching items on your tests, it may well be that you are not putting enough emphasis on the higher-level mental processes.

Other types of objective items. There are other types of objective test items, but these usually are modifications or combinations of the four types discussed above. The teacher occasionally may find it desirable to design a particular type of objective test item to test a specific skill, but you will find that the vast majority of your objective tests will be made up of some combination of these four item types. It generally is wise to include two or more of these item types on any given test, although some teachers use tests of all multiple-choice or all true-false. More important than item type, however, is the problem of matching the test to the teaching objectives--regardless of the item type used.

## The Problem of Validity

Generally speaking, we can say that a test is valid if it measures accurately what it purports to measure. Of course, there are degrees of validity, and documenting the validity of a test can be a complex and difficult process. A reasonable feeling for the validity of a test can be obtained simply by examining the test in the light of the objectives being tested. The more agreement between the test items and the specified outcome objectives, the more valid the test should be. Also, in order to be valid, a test must not only cover the content specified by the objectives, but must cover that content at the behavior level(s) specified or implied.

In summary, there are advantages and disadvantages to both subjective and objective tests. Objective tests are difficult to design, but easy to score and grade. The opposite is true of subjective tests. Objective tests, if not carefully designed, are likely to over-emphasize the two lowest levels of the cognitive domain: simple knowledge (recall, recognition) and application. Subjective tests allow one to test the higher levels of the cognitive domain more easily but suffer in reliability. The type of test which a teacher chooses to use is largely a matter of taste and is not as important as making sure that the resulting test is reasonably valid--that it tests the actual unit objectives. The teacher should always remember that tests should not simply be used as a tool for assigning grades, but as a valuable feedback mechanism which provides data concerning the success of learning experiences.

## STUDY ACTIVITIES

1. Secure a copy of a test included with a popular text in your field. Make a table of specifications for the test based upon your analysis of items on the test and the objectives they appear to measure. Give an assessment of the test and of the individual items on the test.

2. For each type of test item discussed in the preceding section locate (or create) several items for a topic in your subject. Discuss the quality and design of the items. Suggest improvements wherever possible.

## Computer Applications in the Design and Administration of Tests

Two parts of this test construction process can be assisted by computer. These applications apply primarily to the construction and administration of objective tests. The discussion which follows is intended to give the individual teacher general ideas which may be modified or expanded to fit specific needs of the classroom.

## Computer designed tests.

Actually, a computer cannot design test items. Ultimately, a teacher designs the test items--or at least specifies a specific format from which the items are designed. For example, a computer could be used to vary numerical problems by substituting different values for variables in the problem. This way a whole set of problems could be generated from a single template. See ISEAC 12e for details of computer item generation.

What the computer does is to compile a test from a bank of test items according to teacher-specified characteristics. In designing a test-compiling program, one must start by building a bank of test items. Test items can to be designed or gathered from a number of sources and stored in a computer file possibly along with the following item information:

1. the objective which the item tests
2. the type of test item (true-false, multiple choice, etc.)
3. a difficulty factor for each item
4. correct answer(s) for the item

Once a variety of items of differing difficulty and item type have been identified for each learning objective, a computer program is used to construct the item bank and to draw upon that bank in selecting test items according to specifications entered by a teacher.

## Computer administered tests.

An objective test can be administered by a computer interactively provided you have sufficient terminals. Such a test can either be generated or modified by the computer according to specified learner variables, or can be a test composed entirely of predetermined items. A major advantage of a computer administered test is that the computer immediately can score the test as well as administer it and can keep extensive records on the students and the items. The major disadvantage is that taking a test on-line is an expensive use of terminal time. Most schools do not have a sufficient number of terminals to accomodate classes of test-taking students.

If you should find yourself in a teaching situation where terminal time is not a problem, then by all means consider computer administered tests. In designing a test administration program, consider the following:

1. Do you want to permit the student to review or change previous answers?
2. Do you want a time limit on each item? On the test as a whole?

3. Do you want to tell a student when an incorrect answer is selected and permit a second choice at reduced credit?
4. At the conclusion of the test, do you want the computer to tell the student what items were missed and the correct responses?
5. Do you want the computer automatically to assign a grade to a student at the end of the test?
6. Do you want the computer automatically to store the student's grade in an appropriate data file? How about data on the test itself? (i.e., keep a running item analysis)

You should be aware that programs have been developed which permit a teacher with no programming experience to design computer administered tests. These programs permit a computerized test to be changed or modified at will. So, before you expend the effort to develop your own test generation or administration program, check to see what is available from other sources. You may find software available that is compatible with your computer and can be used as is or modified to fit your particular needs.

## Computerized Scoring and Statistical Analysis of Tests

If you have or can get a card reader, you easily can design a test scoring program which will accept and process student answers to objective tests recorded on cards. This particular application of computers in the testing and evaluation program is so powerful and useful that it alone can justify the cost of a mark-sensed card reader.

Refer to Gronlund, 1971 for a detailed discussion of the statistics which are of value to a teacher in analyzing test results and which can easily be calculated using a computer. In ISEAC 22e we present documentation of computer programs for an extensive test analysis and interpretation system. At a much simpler level, we include a program below for doing some test statistics. This particular program requires that the teacher type in the students' names and their test scores. The statistics are then automatically calculated. We have included here both a sample run and a listing of sample test scores without student names. This list could be posted in the classroom for all students to see. Alternatively, the program easily could be modified to accept social security numbers (or some other such code) and to produce a list which could be posted to announce test results.

```
PROGRAM STATS

WELCOME TO STATS.  WOULD YOU LIKE DIRECTIONS?
? YES
THIS PROGRAM WILL ACCEPT THE NAMES AND RAW TEST
SCORES FOR A MAXIMUM OF 200 STUDENTS.
```

```
THE COMPUTER WILL PROVIDE:
   1 - A LISTING OF RAW SCORES AND T-SCORES
       BY STUDENT NAME IN ORDER FROM HIGHEST
       TO LOWEST.
   2 - THE MEAN, MEDIAN, MODE, AND STANDARD
       DEVIATION FOR THE TEST SCORES.
   3 - THE RELIABILITY OF THE TEST.
TYPE DATA IN THE FOLLOWING FORM:

JOHN SMITH, 85

USE ONLY ONE COMMA IN EACH LINE, BETWEEN
STUDENT'S NAME AND TEST SCORE.

IF YOU MAKE A MISTAKE, ON THE NEXT LINE
TYPE THE FOLLOWING:

ERROR,55

WHEN YOU HAVE FINISHED, TYPE THE FOLLOWING:

XXX,55

WHAT IS THE NAME OF THE TEST?
?  CHEMISTRY 6

WHAT IS THE MAXIMUM SCORE ON THE TEST?
?  135
ENTER YOUR DATA NOW.
?  BILL ADDLEMAN,111
?  SUSAN BOWER,133
?  KAREN COWILL,101
?  SAM DUGAN,95
?  JACK EAGAN,122
?  BOB FOWLER,116
?  JIM GAEDE,128
?  KAREN HILL,106
?  SALLY IVERSON,76
?  TOM JACOBS,99
?  GERRY KELLY, 134
?  WAYNE LITTLE,112
?  JAMES MANNING,89
?  MARY NOLAND,100
?  JOHN OLSEN,127
?  TED PAULSEN,131
?  BILL QUINLAN,125
?  EVE RAWLINGS,113
?  XXX,55
```

```
CHEMISTRY 6

STUDENT         RAW SCORE      T-SCORE

GERRY KELLY       134            63
SUSAN BOWER       133            63
TED PAULSEN       131            61
JIM GAEDE         128            60
JOHN OLSEN        127            59
BILL QUINLAN      125            58
JACK EAGAN        122            56
WAYNE LITTLE      119            54
BOB FOWLER        116            52
EVE RAWLINGS      113            50
BILL ADDLEMAN     111            49
KAREN HILL        106            46
KAREN COWILL      101            43
MARY NOLAND       100            42
TOM JACOBS         99            42
SAM DUGAN          95            39
JAMES MANNING      89            35
SALLY IVERSON      76            27

MEAN      MEDIAN      MODE      S.D.         RELIABILITY

112.5     114.5        0        16.1288           0.93

DONE
WOULD YOU LIKE A LISTING OF SCORES WITHOUT
STUDENT NAMES?
?  NO

WOULD YOU LIKE TO RUN THE PROGRAM AGAIN?
?  NO
BYE FOR NOW.
```

(A listing of this computer program is found in Appendix A.)

Before we move on to a discussion of some of the possible applications of a mark-sensed card reader to test evaluation, it may be worthwhile to illustrate the value of T-scores. As mentioned earlier, the T-score is a type of standard score which permits rapid comparisons of test scores. For example, let's say you have given three tests in your course and you see a student with raw scores of: 50, 79, 93. How is he doing? Which test did he do best on? Is he improving?

There is, of course, no way you can answer these questions by looking at raw test scores. Because of our mental set toward test scores, we might assume that he did best on the last test. Let's look at some more data on these three tests:

| | TEST A | TEST B | TEST C |
|---|---|---|---|
| Raw Scores | 50 | 79 | 93 |
| Possible Points | 55 | 90 | 100 |
| Percent Correct | 91% | 87% | 93% |
| Mean | 40 | 80 | 80 |
| Standard Deviation | 5 | 10 | 10 |
| Z-Score | +2.0 | -0.1 | +1.3 |
| T-Score | 70 | 49 | 63 |

If we had recorded the T-scores in the grade book to begin with, we could immediately determine that this student did quite well on Test A and Test C, but only average on Test B. To answer the question, "How well is this student doing?" we can find his average T-score:

70 + 49 + 63 = 182        182/3 = 60.6 or about 61

In other words, this student, on the average, is doing about one standard deviation above the norm on tests. If we remember the relationship between standard deviation and the normal distribution curve we can estimate that this student has done better than 85% of his classmates. In other words, he is doing well.

Some teachers use T-scores directly for the determination of grades. A possible grading scale might be:

| Range of T-Scores | Grade | Approximate % of Students |
|---|---|---|
| 63 - 100 | A | 10 |
| 57 - 62 | B | 15 |
| 43 - 56 | C | 50 |
| 37 - 42 | D | 15 |
| 0 - 36 | F | 10 |

A scale such as this might not be appropriate for use in science classes as it forces 10% of the students to fail, no matter how well they do.

Test scoring via computer. All that we have discussed to this point can be accomplished in less time if a mark-sensed card reader is available. Mark-sensed cards can be used as answer sheets for taking objective tests. Students can record their answers directly on these cards using a soft lead pencil. A program can be prepared to process these cards in batch mode, to score all of the tests, and to print out a list of students and scores (as well as the statistics mentioned in the previous section). A good test scoring program should be designed such that it will accept tests of various lengths, permit the teacher to specify the correct answers on a "key" card, and permit the teacher to specify different weights for different problems.

In Appendix B there is an example of a test scoring program. This program includes many of the options listed above: it accepts tests of various lengths (the length and correct answers are specified on a DATA card), provides a list of student scores, and several statistics (mean, standard deviation, reliability, error, and item analysis). A much more elaborate test result analysis and reporting system is described in ISEAC 22e.

There are several advantages to using the computer to score student answers directly. First of all, if the test answers are recorded directly on mark-sensed cards and then batch processed, there is no need for the teacher to type in any data. The tests can be scored and statistically analyzed in one quick operation. However, more importantly it is now possible to perform an item analysis on the test data. Item analysis provides information on individual test items: information which can be used to improve the test in the future. Briefly, this item information includes the following:

Difficulty factor. This is simply the portion of students getting an item correct expressed as a decimal. Difficulty factors can vary from 0 to 1.0. An item with a difficulty factor of 0.80 should be correctly answered by 80% of the students.

Discrimination factor. The discrimination factor is a number which assumes values between -1.0 and +1.0 and is an indication of how well a particular item identifies the high and low scoring students. It may be calculated by dividing the class into thirds according to the overall raw scores. The number of students in the bottom third of the class getting an item correct is subtracted from the number in the top third of the class getting that item correct. The resulting number is divided by one third of the total number of students. A discrimination factor of +1.0 would mean that every student in the top third of the class got that item correct while every student in the bottom third got it wrong. A discrimination factor of 0 would indicate that equal numbers of students in the top and bottom thirds of a class got the item correct. In other words, that item does not discriminate. Finally, a discrimination factor of -1.0 would mean that the item discriminates perfectly in the wrong direction. All the best students miss it while all the poorer students get it right.

Few items will have discrimination factors of -1.0 or +1.0. Ideally, we would like to see all the discrimination factors for a test large and positive. Items with discrimination factors that are below +.30 don't really add much to the discrimination power of a test and possibly should be rewritten or eliminated.

Item tables. An item analysis table is particularly useful in improving multiple choice items. This is simply a table showing the answers selected by the top and bottom thirds of a class. Here, for example, is what the computer might print:

```
ITEM NUMBER: 18      ANSWER IS: B      DIFFICULTY = 0.36
DISCRIMINATION = +.26

                   A ___ B ___ C ___ D ___ E ___ TOTAL

TOP THIRD          3    17     0     9     6      35

BOTTOM THIRD       8     8     0    10     9     35
```

This table tells us a lot about this particular test item. The difficulty factor is 0.36, which indicates that only 36% of the students are getting this item correct. This suggests the item is rather difficult. The discrimination factor is low. The item is discriminating positively, but is not really a very strong item. The item needs to be improved.

The table itself indicates that none of the students in either the top or bottom thirds of the class chose alternative "C". Alternative "C" is not contributing to the item and should be rewritten or simply eliminated. Alternative "D" was selected by 10 of the poorer students, but 9 of the best students also selected it. This alternative is causing confusion among all students and should be examined carefully. If the nine students in the top third who selected this item got the correct answer (B) instead, the discrimination of the item would rise to +.52--a considerable improvement. Alternative "A" seems okay--while it is distracting a few of the better students, it is distracting more than twice as many of the poorer students. Alternative "E" is not as good and also should be examined.

Of course, it is impossible to determine the exact cause of difficulty with an item just by looking at an item analysis table. However, when you examine test items with a table such as this handy, you often can get a good idea of how an item might be improved.

A teacher could do all of this without a computer, but it would take hours of calculating. Teachers are not likely to spend such amounts of time analyzing a test. However, as a side benefit of a test scoring program, teachers do analyze and improve the tests they construct, and tend to test more frequently.

Finally, it should be re-emphasized that any teacher in any class can use programs like the ones described in this chapter without previous computer experience. You may wonder why the science teacher should encourage other teachers to use the computer facilities--after all, the more teachers using the computer, the more difficult it is to get it when you want it. Remember, the more the computer is used, the more likely the administration is to spend more money on computer hardware and software. So it really is to your advantage to encourage other faculty to use computer facilities in their teaching.

## COMPUTER APPLICATIONS TO THE INDIVIDUALIZATION OF SCIENCE INSTRUCTION

Since the mid 1960's there has been a growing interest among science educators in the individualization of science instruction. There has been a number of funded curriculum development projects focused on the development of curricula which lend themselves to individualized instructional techniques.

Fundamental to individualized approaches to education is the assumption that students are unique individuals with differing aptitudes, interests, rates and styles of learning. It also is assumed that all students have the capacity to learn but the extent of this capacity varies from one individual to another.

The conventional classroom seldom provides for individual differences. A teacher who bases a chemistry course around teacher-centered presentations (lectures) generally plans lessons with the student of "average" ability in mind. The most able students may be bored with these presentations while the less able may be left behind in a state of confusion. Theoretically, teachers should deal with this disparity in learning rates by providing enrichment activities for the brighter students while giving additional help to the slower learners. Realistically, however, teachers seldom have the time in a class to provide either.

In the recent past, the emphasis in science education has been on preparing students for a career as scientists. Today, however, most teachers feel that the primary goal of a science curriculum should be the encouragement of science literacy among all students. Due to the wide range of ability levels found in the student population, individualizing the curriculum may appear to be the best method of achieving these goals. A major difference between the conventional approach to classroom instruction and individualized programs is the role of the teacher. In the conventional class, the teacher assumes the role of an expert in the field and a provider of learning. In an individualized plan the teacher becomes more of a consultant and facilitator of learning. Indeed, in a well-run individualized program, the teacher often is seen by students as being a partner in learning. In an individualized plan there are fewer formal group lectures. Class time generally is spent with students working individually or in small groups with the teacher consulting with them individually. The teacher might also spend part of the class period evaluating student work or in prescribing specific learning tasks. Occasionally the teacher may be needed by none of the students as they work independently during class.

Let's examine a hypothetical science course and the ways in which a teacher might individualize the course. Suppose that you've been assigned to teach a general science course at the ninth grade level. We will stipulate that this is to be a required course for all but advanced students. For some students, this will be the terminal science course, while others probably will enroll in biology during their sophomore year. You have textbooks for all of your students and some laboratory equipment--not enough, however, for all of your students to do the same experiment at the same time. Since the course is required for all but the brightest students (who are placed directly in biology their freshman year), you can reasonably expect a wide distribution of abilities and interest. Suppose, now, that you've decided that you want to teach this course on an individualized basis. How might you begin? What problems might you expect to encounter during the year? What advantages could you reasonably expect? Finally, how might a computer be utilized to assist with this course? Let's examine these questions one at a time.

## Setting Up an Individualized Instruction Program

The first step in setting up an individualized instruction program is the same as the first step in planning any course taught the conventional way: you must specify outcome objectives. While one occasionally may hear teachers claim that they "do not bother with objectives", it is absolutely critical that the teacher designing an individualized course spend considerable time in deciding *exactly* what students should be able to *do* at the conclusion of the course. These objectives should be clearly worded and stated in behavioral terms. In individualized programs, the students assume a major part of the responsibility for their own learning. Thus, it is essential that the students understand perfectly what is expected of them. Without this understansing, the students may be confused and unsure of what to do. Refer to Mager, *Writing Behavior Objectives*, for a detailed discussion on preparing behavioral objectives.

From the view of a mythical general science course, the first task in individualizing the course is to make up a list of specific objectives for the course. Once this is done the next task is to cluster the objectives into sets (units, packets, modules, etc.) of instruction and to begin producing the actual written materials which form the backbone of the course.

## The Construction of Learning-Activity Packets

It is possible that after having compiled a list of objectives for a complete general science course, you may have a hundred or more such statements. The second step in the process of individualizing a course is to break this list of objectives up into manageable pieces organized into what we shall refer to here as learning-activity packets (LAPS for short). A typical LAP at the secondary level might include approximately 5 specific, but related, objectives and be designed to occupy approximately 10 class days from start to finish. The organization of a LAP can be varied according to the individual tasks of the teacher, but here are some things which might be included:

1. Cover page/title.
2. List of objectives to be accomplished.
3. Rationale for the objectives (Why bother to learn this?).
4. Pre-test and corresponding answers.
5. Narrative (textual) section.
6. List of learning resources, including test, other books, films, filmstrips, articles, taped lectures/directions, experiment materials.
7. List of suggested learning activities--exercises, experiments, etc.
8. Suggested extensions beyond the minimum required work.
9. Sample evaluative post-test with answers provided.
10. Suggested next LAP.

At least two of the above suggested ingredients are essential in any LAP: the objective list (2) and a list of learning resources available (6). The other items in this list can be considered desirable, but optional, additions to these two essential parts.

Many teachers start using learning-activity packets by developing them for only one part of a course at a time. It is possible to begin individualizing a course by preparing packets for one or two units, with the idea of adding more and more LAPS in coming years. Others find it possible to prepare LAPS for an entire course over a summer. There are commercially available packets, but they have not been highly successful. Locally produced LAPS have an advantage in that they can be precisely tailored to local needs, facilities, and objectives. Once a teacher has designed a learning-activity packet, it generally is duplicated in class quantities.

## Using LAPS to Individualize Instruction

Let's return now to the hypothetical general science class which you are individualizing. Suppose that you have developed twenty-five learning packets, each designed to occupy about ten class days and each based on approximately five to ten outcome objectives. Now how do you employ these in an individualized course? Again, there are many different systems which can be used. We'll examine a couple of possible approaches. To make the discussion easier, let's assume that the list below represents the twenty-five LAPS.

LEARNING-ACTIVITY PACKETS FOR GENERAL SCIENCE

| LAP NUMBER | TITLE/TOPIC |
|---|---|
| 1. | What is Science? |
| 2. | The Scientific Method |
| 3. | Using Laboratory Equipment |
| 4. | The Metric System |
| 5. | The Atom |
| 6. | Elements, Compounds, and Mixtures |
| 7. | The Periodic Table |
| 8. | Chemical Reactions |
| 9. | Heat--Kinetic Molecular Theory |
| 10. | Light and Optics |
| 11. | Newton's Laws of Motion |
| 12. | Energy--Kinetic and Potential |
| 13. | Conservation in Nature--Mass and Energy |
| 14. | The Energy Crisis--Is Civilization Doomed? |
| 15. | Electricity |
| 16. | What is Life? |
| 17. | The Cell--Unit of Life |
| 18. | Simple One-Celled Organisms |
| 19. | DNA--Code of Life |
| 20. | Mitosis and Meiosis |
| 21. | Evolution of the Species |
| 22. | Plants--Elements of Botany |
| 23. | Human Reproduction |
| 24. | Heredity |
| 25. | Biochemistry of Nutrition |

What you have produced only makes the individualization of the course *possible.* The way in which you choose to employ these LAPS will determine to what extent the course actually is individualized.

*Individualizing Through Student Pace.* One of the most common approaches to the use of learning-activity packets in individualizing a course of instruction is to permit students to set their own pace through the materials. Using this system, a teacher probably would begin the school year with a day or two of orientation to the course and materials. Students would then begin working on LAP 1. They would request an evaluation whenever they had accomplished the objectives contained in that packet.

Upon successful completion of the evaluation on LAP 1, the student would proceed to LAP 2. This process would continue throughout the course.

The above approach is not without difficulties. However, it does, at least to a limited extent, provide for individual differences. Some educators have criticized this approach as being too narrow. Harry Wong, a well-known science teacher and author of science textbooks for the less-able student, has compared this approach to individualization with a travel agent who only offers trips to Rome. This agent offers a five-day trip, a two-week trip, and a four-week trip--all to Rome. The agent claims that longer trips can be arranged, but the itinerary is exactly the same no matter what trip you choose. Only the length of time is different; everybody goes to Rome. It is likely that such a travel agent would not stay in business long. The analogy is not perfect, but it does illustrate a fundamental shortcoming of individualizing exclusively through student pace.

Individualizing Through Sequence. Our general science course can be individualized still more by permitting students some choice in the path which they employ in working through the modules. Of course it must be recognized that in most science courses which have been structured around learning packets, there will be some packets which must be completed before others, so complete freedom of sequence generally is not possible.

Looking at our list of twenty-five modules, we might conclude that the first four should be done in order at the very beginning of the course. After completing the first four LAPS, we perhaps could permit students to do either LAP 5, which starts a sequence of physical science packets or, alternatively, to skip to LAP 16, the first of a series of biological science packets.

In this particular set of materials, it is unlikely that a student could be very successful with LAP 19 (DNA) without previously completing LAP 5 (The Atom), LAP 6 (Elements, Compounds, Mixtures) and LAP 8 (Chemical Reactions). This information can be presented by adding a list of prerequisite packets to the cover sheet/title page of each of the packets. With prerequisites stipulated, the students could be informed that they may follow any sequence after completing the first four packets, provided they observe the prerequisite guidelines.

Individualizing Through Packet Selection. If you will recall, we hypothesized that each of the twenty-five general science LAPS we have been talking about were designed for approximately 10 class days of activities. Of course, this would be an average figure. Some of the LAPS might be completed in a much shorter time while others might take considerably longer. However, if this were the average time spent by a student per packet, it is easy enough to calculate that we have enough material here for 250 class days, more than a typical school year. We have much more material than the typical student can reasonably be expected to complete. We might reasonably expect most students to complete 16 of the packets in an academic year. Allowing for the slower students, we might tell them at the beginning of the course that they would be expected to complete 13 or 14 packets in order to receive credit for the course. With this in mind, the next question is what packets should the student complete? You may feel that certain of the packets cover topics which are of such great importance that in no way could a student be given credit for general science unless the objectives related to that topic are met. These packets are required. Everyone MUST do these packets. Among the others, there might be a minimum number to complete, but the student chooses these. The teacher, through daily individual consultations, facilitates these selections.

*Other Methods of Individualizing.* The preceeding discussion is by no means exhaustive. There are many other methods of individualizing instruction. Our purpose here is to explain but one method of setting up an individualized instruction system so that you can appreciate the assistance which a computer can give to such a program. If, in your teaching, you choose to individualize a course, many modifications of the previously described plan will occur to you. Here are just a few of other alternatives which have been tried successfully in the past:

1. An individualized approach based on module production contracts drawn up mutually by the student and teacher.
2. Some teachers using individualized instruction order a few copies each of several different textbooks per class, rather than many copies of the same text. The books are kept available in the classroom to be checked out by students. This permits the teacher to have books of different reading levels in the same subject. The LAPS contain information in the resources section on what pages in each of the texts relate to the topic dealt with in the packet.
3. Some teachers permit students to write their own learning objectives. This permits each student to design his/her own course. This approach is not for the teacher who feels knowledge of certain facts and skills is sacred. A student might choose to ignore one of these areas. This approach is perhaps an ultimate in individualization and requires mature learners for success.

## STUDY ACTIVIES

1. List what you feel to be some advantages of individualized science instruction as described here.

2. List what you feel to be disadvantages of individualized instruction.

## COMPUTER MANAGED INSTRUCTION (CMI)

In the previous section we discussed the characteristics of individualized instruction as it might apply to teaching the sciences. Now we shall investigate applications of a computer to such an instructional style. A very detailed discussion of CMI is contained in ISEAC 11e. Here we confine our discussion to instruction in the sciences.

The most important distinguishing characteristic of CMI is that the computer is used to provide clerical and management assistance to the teacher rather than actually conducting instruction as in other instructional styles. Since the computer is not used to present large amounts of information, the terminal time required per student is less than in other computer instructional styles. Thus, the costs of CMI usually are lower and the hardware requirements are fewer. With the assistance of a computer, a teacher is able to individualize courses beyond what would normally be possible without computer assistance. In many ways, it could be argued that, with present technology, computer managed instruction represents the most efficient use of computers in instruction today.

Following are ways in which a computer might be utilized to assist with an individualized program. You should be aware that while there are commercially available CMI program packages, none of the presently available programs contains all of these features.

Testing and Evaluation. One of the most obvious things that a computer might do is the testing and evaluation of students on each study packet. There are a number of alternatives which need to be considered. For example, the simplest way to utilize a computer in the testing and evaluation of students would be to have an objective test for each packet prepared on paper and have the student record answers on mark-sensed cards. The card would be read by the computer and the test scored. The computer would either inform the student of success on the evaluation, or relate specifically what objectives were not met. Additionally, the program would store data about the tests taken by each student. This feature generally permits the teacher to ask at any time for a listing of the tests taken by each student, the dates of the tests, and the scores. A very simple CMI program, such as this, would save the teacher considerable time in managing an individualized course.

As an alternative, the computer can be used to administer the tests. In other words, the questions making up each test can be stored in the computer and presented to the student interactively. The advantage to this approach lies in saving the teacher from having to pull tests from files every day. A main disadvantage is that there could be a problem with test security, but this can be overcome by adding a codeword to the test administration program which would have to be entered by the instructor before each session. Another major disadvantage, however, is that taking a test on-line effectively ties up a terminal for a rather extended period of time. Unless a teacher has access to a number of terminals, it probably is impractical to select on-line testing. In the case where the teacher has but a single terminal, the use of printed tests with mark-sensed card answer forms probably is the more sensible approach.

Still a third alternative use of computers in managing the testing program of an individualized course of study is in the generation of individualized tests. A computer could produce tests for a particular topic which vary in difficulty according to some predetermined parameter. Such a program would draw upon a bank of items previously constructed by the teacher. Such tests could be presented and scored in interactive mode or could be printed by a printing terminal for card responding and batch scoring.

Scheduling of Classroom Resources. One of the problems which can occur in the individualized science class is conflict in the use of classroom resources, particularly laboratory equipment. In other words, from time to time more than one student may wish to use a given piece of lab equipment. In a computer managed individualized course, the computer can be used to eliminate conflicts through the scheduling of these resources. The CMI software can be adapted to permit students to "sign up" for resources at a particular time. It perhaps should be mentioned that in the individualized class the teacher is a very valuable resource. The teacher's time also can be scheduled in this manner. (e.g., students can schedule appointments with the instructor through the computer, the computer keeping track of all available times and appointment information.) If such a package is utilized, it should have the capability to produce a daily list of data concerning scheduled resources for the instructor. (An example of such a resource scheduling program is described in ISEAC 26e.)

The Prescription of Course of Study. More sophisticated CMI systems may include individual pre-testing and prescribing of a specific course of study for the student based on pre-test results. As an example, consider the fourth LAP in the hypothesized list of packets for the general science course described earlier--The Metric System. This packet might cover a great deal of information which students had encountered earlier. A computer would facilitate giving each student an objective pre-test on the metric system. The computer could evaluate the pre-test answers and then prescribe a specific course of study designed to remediate any areas of weakness. The same program should keep data for the teacher's information on the current prescription for each student in the class.

Scheduling of Discussion Groups. One of the real disadvantages in any individualized instruction system is that it is difficult for students to discuss topics of common interest in groups. Since students are working in different parts of the course, small group discussions have to be scheduled in advance. A CMI system can help with this task by allowing students to indicate topics which they would like to discuss and subsequently handle the scheduling of appropriate group discussions.

## A Summary of Possible CMI Features

The following summary is included to suggest to you the variety of CMI software packages which could be produced. The combinations and permutations of the possible features, even with limited hardware, are almost endless. While it would be hoped that the teacher who wishes to use CMI would not be responsible for software development, the teacher does need to be familiar enough with the possible features of a CMI package to be able to specify exactly what is wanted.

I. DATA STORAGE CAPABILITIES
Store and provide for instructor retrieval:
- A. Student name and identification information
- B. Test scores and grades
- C. Dates of testing
- D. Number of tests taken
- E. Current study prescription
- F. Standardized test scores for each student (i.e.IQ, aptitude, etc.)

II.TEST GENERATION AND SCORING
- A. On-Line Testing
  1. Administer "canned" test, record responses, grade and store score.
  2. Administer individualized test made up of items selected from item bank, record responses, grade and store score data.
- B. Off-Line Testing
  1. Allow students to enter test number code and answers.

Grade exam, inform student of score, record appropriate data.

III. DETAILED PERFORMANCE ASSESSMENT

- A. Diagnostic testing providing continuous evaluation of course materials.

IV. FEEDBACK OPTIONS TO STUDENT

- A. Provide immediate test performance feedback.
- B. Provide highly detailed analysis of student performance.
- C. Most common feedback is the listing of educational objectives mastered and unmastered.
- D. Feedback not oriented toward the subject matter, but toward the cognitive level of successful and unsuccessful performance. (E.g., tell the student he/she is doing well learning factual information, but having difficulty applying concepts in new situations.)

V. TAILORED TESTING

- A. Update the student's test score immediately after each question; terminate testing when score reaches mastery criterion or becomes too low to pass.
- B. Elaborate schemes used to select each test question on the basis of previous performance.
- C. Construction of tests of specified difficulty.

VI. STUDY PRESCRIPTION GENERATION

- A. Determine the current status of each learner.
- B. Prescribe specific learning objectives based on an analysis of a pre-test.
- C. Offer the student a choice of media from an on-line library of learning resources.
- D. Keep a record of media selections, provide feedback on the effectiveness of each medium for the student.
- E. Alternatives to resource selection:
  1. Computer prescribes specific learning resources
  2. Student indicates preferences and computer supplements
  3. Student has complete freedom in selecting learning resources

VII. SCHEDULING AND RESOURCE ALLOCATION

- A. Coordination of following activities:
  1. On-line testing
  2. Laboratory equipment
  3. Teacher time
  4. Small group discussions
  5. Media facilities
- B. Provide advance notice to instructor to allow for the preparation of needed laboratory equipment, etc.
- C. Keep record of time spent by students on equipment/resource utilization.

VIII. INDIVIDUALIZATION THROUGH CONTRACTS

- A. Design an individual program specifying both content and level of achievement based on student input. Options:
  1. Instructor and student can build the contract

together.
        2. Student can build his own within the predefined limits of the instructor.
    B. Allow for changes to the contract.
    C. Provide the instructor with data on current contracts for each student.

IX. MESSAGE CAPABILITIES
    A. Students may leave a "message" for the instructor.
    B. The instructor may leave messages for an individual student or for a group of the class.
    C. Students may leave messages for each other.
    D. Interterminal talk between students and/or the instructor.

## Summary

Individualized approaches to the teaching of science have been increasing in popularity since the mid 1960's. Most individualized systems are based on learning packets (sometimes called modules, units, contracts) which are designed locally. The design of learning packets is highly specific to classroom needs and the only really essential ingredients include a list of specific learning objectives and a list of resource materials.

Learning packets can be used in a variety of ways. The most common approach is to permit students to procede through a series of packets at their own rate. More advanced systems allow students some control over the sequence of packets studied as well. Even more open systems have been tried in which the student sets his/her own objectives for a course.

The management of individualized programs can be assisted greatly with a computer. Such applications of computers are frequently referred to as Computer Managed Instruction (CMI). The variety of ways in which a computer can assist with the management of an individualized course almost is endless. The most important distinguishing feature of CMI is that the computer is used to provide management assistance to the teacher, rather than actually conducting teaching activities. CMI represents one of the most efficient applications of computer systems to the instructional process and may be the most effective way to utilize a computer to improve the instruction in a school.

## QUESTIONS FOR DISCUSSION

1. Do you think that a particular field of science (i.e., chemistry) would be more difficult to individualize than others? Why or why not?

2. Suppose you had the following hardware to be used to assist with the individualization of a science course: micro-processor with 64K bytes memory; 1 mark-sensed/punch card reader; 1 cassette tape program storage unit; 1 standard teletype interface. What types of features would you want in a CMI software package to be run on this equipment? What features would you not want? Why?

3. You are a new teacher at a large suburban high school. You would like to individualize your general science class, but individualized teaching techniques presently are not being used within the science department, possibly due to the fact that the department chairman tends to be a bit conservative in his thinking. What arguments might you present for moving toward an individualized approach?

4. How do you think the grading of students in an individualized course should be handled? Should students be graded only on the basis of results, or should the students' abilities be considered in assigning a grade?

5. Do you think that students should be permitted to help one another in an individualized course? Why or why not?

6. Can you think of any ways that a computer could assist with an individualized course that are not mentioned in this chapter? If so, explain them.

## ACTIVITIES

1. Take a chapter from a science textbook and construct a brief learning packet based on the content of that chapter.

2. Write a set of learning objectives which could be the basis of a learning-activity packet on the metric system.

3. Examine a CMI software package your instructor names. You will be told how to access this program. Go through it as a student and then examine the instructor options. What do you like about this system? What do you dislike? If you were going to modify the system, what changes would you make?

4. Visit an individualized classroom, preferably one where CMI is used. Your instructor will make the appropriate arrangements for this, if possible. Interview a few of the students and get their reaction to this mode of learning. Spend time observing and noting the conditions arising in this environment that normally are not encountered in the conventional classroom.

# APPENDIX A

## Listing of a Test Statistics Program

```
PROGRAM STATS

00100 REM TEST STATISTICS FOR TEACHERS
00110 PRINT"WELCOME TO STATS.  WOULD YOU LIKE DIRECTIONS?"
00120 INPUT A$
00130 IF SUBSTR(A$,1,1)="N" THEN 420
00140 REM DIRECTIONS
00150 PRINT"THIS PROGRAM WILL ACCEPT THE NAMES AND RAW TEST"
00160 PRINT"SCORES FOR A MAXIMUM OF 200 STUDENTS."
00170 PRINT"THE COMPUTER WILL PROVIDE:"
00180 PRINT"           1 - A LISTING OF RAW SCORES AND T-SCORES"
00200 PRINT"               BY STUDENT NAME IN ORDER FROM HIGHEST"
00210 PRINT"               TO LOWEST"
00220 PRINT"           2 - THE MEAN, MEDIAN, MODE, AND"
00230 PRINT"             STANDARD DEVIATION FOR THE TEST SCORES."
00240 PRINT"           3 - THE RELIABILITY OF THE TEST."
00250 PRINT
00260 PRINT
00270 PRINT"TYPE DATA IN THE FOLLOWING FORM:"
00280 PRINT
00290 PRINT"JOHN SMITH, 85"
00300 PRINT
00310 PRINT"USE ONLY ONE COMMA IN EACH LINE, BETWEEN"
00320 PRINT"STUDENT'S NAME AND TEST SCORE."
00330 PRINT
00340 PRINT"IF YOU MAKE A MISTAKE, ON THE NEXT LINE"
00350 PRINT"TYPE THE FOLLOWING:"
00360 PRINT
00370 PRINT"ERROR,55"
00380 PRINT
00390 PRINT"WHEN YOU HAVE FINISHED, TYPE THE FOLLOWING:"
00400 PRINT
00410 PRINT"XXX,55"
00420 PRINT
00430 PRINT"WHAT IS THE MAXIMUM SCORE ON THE TEST?"
00470 INPUT K
00480 PRINT"ENTER YOUR DATA NOW."
00490 REM STORE DATA
00500 DIM N$(200),S(200)
00510 REM N= NR.  SCORES, N$=NAMES, S=RAW SCORES, I=COUNTER
00520 N = 0
00530 I = 1
00540 INPUT N$(I), S(I)
00550 IF N$(I)="ERROR" THEN 00600
00560 IF N$(I) = "XXX" THEN 00640
00570 N = N+1
00580 I = I+1
00590 GOTO 00540
```

```
00600 N = N-1
00610 I = I-1
00620 GOTO 00540
00630 REM SORT STUDENTS BY RAW SCORES
00640 FOR Z = N TO 2 STEP -1
00650 FOR I = 1 TO Z-1
00660 IF S(I)>S(I+1) THEN 00730
00670 T = S(I)
00680 S(I) = S(I+1)
00690 S(I+1)=T
00700 T$ = N$(I)
00710 N$(I) = N$(I+1)
00720 N$(I+1) = T$
00730 NEXT I
00740 NEXT Z
00750 REM FIND MEAN OF RAW SCORES (M1)
00760 M1 = 0
00770 FOR I = 1 TO N
00780 M1 = M1+S(I)
00790 NEXT I
00800 M1 = M1/N
00810 REM FIND STANDARD DEVIATION OF RAW SCORES (M2)
00820 B = 0
00830 FOR I = 1 TO N
00840 A = S(I) - M1
00850 A = A*A
00860 B = B+A
00870 NEXT I
00880 M2 = SQR(B/N)
00890 REM CALCULATE T-SCORES
00900 REM Z=Z-SCORE, T=T-SCORE
00910 DIM T(200)
00920 FOR I = 1 TO N
00930 Z = (S(I)-M1)/M2
00940 Z = Z*10+.5
00950 Z = INT(Z)
00960 T(I) = 50+Z
00970 NEXT I
00980 REM FIND MEDIAN OF RAW SCORES (M3)
00990 IF INT(N/2) = (N/2) THEN 01030
01000 W = N/2+.5
01010 M3 = S(W)
01020 GOTO 01060
01030 W = N/2
01040 M3 = (S(W)+S(W+1))/2
01050 REM FIND MODE OF RAW SCORES (M4)
01060 Q = S(1)
01060 R = 1
01090 R1 = 1
01100 FOR I = 1 TO N
01110 IF S(I) = S(I+1) THEN 01180
01120 IF R1  R2 THEN 01150
```

```
01130 R = R1
01140 Q = Q1
01150 Q1 = S(I+1)
01160 R1 = 1
01170 GOTO 01190
01180 R1 = R1 + 1
01190 NEXT I
01200 IF R = 1 THEN 01230
01210 M4 = Q
01220 GOTO 1250
01230 M4 = 0
01250 R1 = K/(K - 1)
01260 R2 = M1*(K-M1)
01270 R3 = K*M2*M2
01280 R = R1*(1-R2/R3)
01290 R = R*100+.5
01300 R = INT(R)
01310 R = R*.01
01320 REM OUTPUT
01330 PRINT
01340 PRINT B$
01350 PRINT
01360 PRINT"STUDENT","RAW SCORE","T-SCORE"
01370 PRINT
01380 FOR I = 1 TO N
01390 PRINT N$(I),S(I),T(I)
01400 NEXT I
01410 PRINT
01420 PRINT
01430 PRINT"MEAN"," MEDIAN", "MODE","S.D.","RELIABILITY"
01440 PRINT
01450 PRINT M1,M3,M4,M2,R
01460 PRINT
01470 PRINT
01480 PRINT"DONE"
01490 PRINT"WOULD YOU LIKE A LISTING OF SCORES WITHOUT"
01500 PRINT"STUDENT NAMES?"
01510 INPUT Q$
01520 IF SUBSTR(Q$,1,1) = "Y" THEN 01540
01530 GOTO 01670
01540 PRINT
01550 PRINT
01560 PRINT"RAW SCORE","T-SCORE"
01570 PRINT
01580 FOR I = 1 TO N
01590 PRINT S(I),T(I)
01600 NEXT I
01610 PRINT
01620 PRINT
01630 PRINT"MEAN"," MEDIAN", "MODE","S.D.","RELIABILITY"
01640 PRINT
01650 PRINT M1,M3,M4,M2,R
```

```
01660 PRINT
01670 PRINT
01680 PRINT"WOULD YOU LIKE TO RUN THE PROGRAM AGAIN?"
01690 INPUT Z$
01700 IF SUBSTR(Z$,1,1) = "Y" THEN 00460
01710 PRINT"BYE FOR NOW."
01720 END
READY
```

# APPENDIX B

## Listing of a Test Item Analysis Program

PROGRAM ITEMAN

```
00100 DIM C(100),N$(100),S$(100), A(100,100),T(100)
00105 DIM U(5),L(5),F(100)
00110 READ N,I
00120 FOR X = 1 TO I
00130 READ C(X)
00140 NEXT X
00150 FOR X = 1 TO N
00160 READ N$(X),S$(X)
00170 FOR Y = 1 TO I
00180 READ A(X,Y)
00190 NEXT Y
00200 NEXT X
00210 FOR X = 1 TO N
00220 FOR Y = 1 TO I
00230 IF A(X,Y) = C(Y) THEN 00250
00240 GOTO 00270
00250 A(X,0) = A(X,0)+1
00260 F(Y) =F(Y)+1
00270 NEXT Y
00280 A(0,0) = A(0,0)+A(X,0)
00290 B = B+(A(X,0)*A(X,0))
00300 NEXT X
00310 M = A(0,0)/N
00320 S1 = A(0,0)*A(0,0)
00330 S = SQR(B-(S1/N))/(N-1))
00340 FOR X = 1 TO N
00350 L = A(1,0)
00360 J = 1
00370 IF N = 1 THEN 00430
00380 FOR Y = 1 TO (N-x+1)
00390 IF A(Y,0) = L THEN 420
00400 L = A(Y,0)
00410 J = Y
00420 NEXT Y
00430 A(J,0) = A(N-X+1,0)
00440 A(N-X+1,0) = L
00450 FOR Z = 1 TO I
00460 P = A(N-X+1,Z)
00470 A(N-X+1,Z) = A(J,Z)
00480 A(J,Z) =P
00490 NEXT Z
00500 P$ = N$(N-X+1)
00510 N$(N-X+1) = N$(J)
00520 N$(J) = P$
00530 P$ = S$(N-X+1)
00540 S$(N-X+1) = S$(J)
```

```
00550 S$(J) = P$
00560 NEXT X
00570 FOR X = 1 TO N
00580 T(X) = (((A(X,0)-M)/S)*10)+50
00590 NEXT X
00600 PRINT"STUDENT      SS NO.         SCORE        T-SCORE
PERCENT"
00610 PRINT"-----------------------------------------------------"
00620 FOR X = 1 TO N
00630 PRINT"STUDENT      SS NO.       SCORE      T-SCORE";
00635 print"PERCENT"
00640 PRINT
00650 NEXT X
00660 PRINT
00670 PRINT
00680 PRINT"MEAN =";M
00690 PRINT"STANDARD DEVIATION = ";S
00700 I1 = (I/(I-1))
00710 I2 = M*(I-M)
00720 I3 = I*S*S
00730 B = I1(1-(I2/I3))
00740 PRINT"ESTIMATED RELIABILITY = ";R
00750 E = S*(SQR(1-R))
00760 PRINT"STANDARD ERROR = ";E
00770 PRINT
00780 PRINT
00790 PRINT
00800 PRINT
00810 PRINT
00820 C = ROF(N/3)
00830 FOR X = 1 TO I
00840 FOR Y = 1 TO C
00850 U(A(Y,X)) = U(A(Y,X))+1
00860 NEXT Y
00870 FOR Y = (N-C+1) TO N
00880 L(Z(Y,X)) = L(A(Y,X))+1
00890 NEXT Y
00900 D = (U(C(X))-L(C(X)))/C
00910 PRINT"ITEM NR.";X'TAB(25)'"CORRECT ANSWER = ";C(X)
00920 PRINT"DIFFICULTY = ";(F(X)*100)/N
00930 PRINT"DISCRIMINATION FACTOR = ":D
00940 PRINT"RESPONSE:      1      2      3      4      5"
00950 PRINT"-------------------------------------------"
00960 PRINT USING "UPPER THIRD",U(1),U(2),U(3),U(4),U(5)
00970 PRINT
00980 PRINT "LOWER THIRD", L(1),L(2),L(3),L(4),L(5)
00990 PRINT
01000 PRINT
01010 MAT U = ZER
01020 MAT L = ZER
01030 NEXT X
01040 STOP
```

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